Effects of Meal Size and Correction Technique on Gastric Emptying Time: Studies with Two Tracers and Opposed Detectors

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Geometric-mean correction of gastric radioactivity can be used to correct for the distribution, depth, and attenuation of the radionuclide. Anterior image counts were compared with the geometric mean of anterior and posterior counts, using a computer-assisted gamma camera. Phantom and human studies using Tc-99m and In-111 were used to evaluate the difference between anterior-only and geometric-mean data.

The effect of meal size on gastric emptying was studied using Tc-99m and In-111 simultaneously as solid-phase and liquid-phase markers. Differences between the anterior data and AP-PA data corrected by geometric mean were compared in ten healthy male subjects. The average half-emptying times for solid food, with 1692-, 900-, and 300-g meals, were 277, 146, and 77 min, respectively. Average half-emptying times for liquid were 178, 81, and 38 min for the same meals.

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Radionuclide gastric emptying studies are generally performed from the anterior view alone, with no attempt to correct for depth or attenuation (*1–3*). Recent studies (*4–6*) have used a dual-probe rectilinear scanner to correct for the changing radionuclide distribution within the stomach and alterations in attenuation for Tc-99m and In-113m. The attenuation and depth variation can be corrected by calculating the geometric mean of two counts (square root of their product) measured from AP-PA scans (*7, 8*). We have investigated the effects of depth and attenuation using Tc-99m and In-111 in phantoms. We have also compared the data from the anterior projection with the data by corrected geometric mean in subjects undergoing gastric emptying studies. For this we used Tc-99m to mark the solid phase, with In-111 concurrently marking the liquid. These results have been applied to study the effects of meal size on gastric emptying.

METHODS

The possibility of using Tc-99m and In-111 simultaneously was examined by counting point sources of each radionuclide in air and water. Each source was positioned 8 cm from the camera's collimator and counts were taken using a 20% energy window centered at 140 or 247 keV. Counts into the 140-keV window from In-111 were 24% of the 247-keV count in air and 56% in water. With the Tc-99m source, counts into the 247-keV window were less than 0.2% of the 140-keV counts in both air and water.

Labeling stability. Chicken liver labeled with Tc-99m sulfur colloid (*1*) was selected as a marker for solid-food gastric emptying. Indium-111 DTPA simultaneously marked the liquid phase. An in vitro study was performed to determine the fraction of Tc-99m that would leach into the liquid phase and the fraction of In-111 that would become bound to the solids. Two 900-g meals (200 g beef stew, 200 g applesauce, 50 g bread, 225 g fresh orange juice, and 225 g whole milk) were each mixed with 300 cc gastric juice (pH 1.33) from a normal subject. In-111 DTPA was added to one meal gastric-juice mixture and Tc-99m liver was added to the other. Each was then mixed in a blender for 1 min, then placed in a 37°C water bath. Aliquots were taken at 1-hr intervals for 5 hr. Samples were centrifuged at 1600 *g* for 20 min and the supernatant withdrawn. The pellet was resuspended in 3 cc normal saline and centrifuged again. The supernatant was again withdrawn and the new pellet washed with 30 cc of saline through several layers of gauze. The solid residue and wash plus supernatants were counted and compared with standards of known radioactivity for each radionuclide.

To determine the amount of Tc-99m appearing in liquid without mechanical blending, 3 g Tc-99m-labeled chicken liver was cooked, finely diced, and mixed with 100 cc water and 300 cc gastric juice. The mixture was incubated at 37°C and agitated gently every 5

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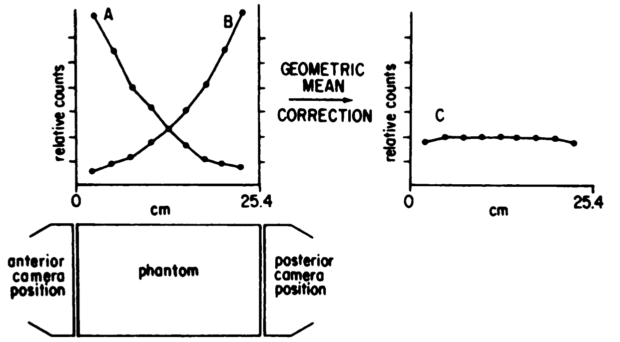

FIG. 1. Examples of sensitivity at depth for Tc-99m point source in tissue-equivalent polystyrene phantom. Counts were obtained with source at various depths for anterior (A), posterior (B), and geometric-mean (C) corrected counts. Geometric-mean correction provides uniform sensitivity that is independent of depth.

min. Aliquots of the liquid were taken at 1-hr intervals for 5 hr, each was filtered and counted against a known standard.

Phantom studies. All imaging was performed with a 410-keV diverging collimator. The uniformity to a sheet source at 10 cm was ±9.6% across the central 80% of the field, and no data were taken from outside this central area.

To investigate the accuracy of geometric-mean correction, the following phantoms were constructed: (a) tissue-equivalent polystyrene sheets ($\rho \sim 1.06$ g/cc), (b) water bath surrounding a 300-cc source, and (c) variable volume source in a water bath.

Phantom (a) was a horizontal stack of ten tissue-equivalent polystyrene sheets, 2.54 × 34 × 34 cm (Fig. 1). Camera images were made of a small Tc-99m source placed successively in each interface, imitating depths from 2.54 to 22.86 cm. Decay corrections were applied as needed. The series was repeated with In-111, all images being stored on magnetic disk for the computer's geometric-mean calculation.

Phantom (b) was a cylindrical water bath, 25 cm in diameter by 25 cm high, with a 300-cc polyethylene cylinder, 5 cm in diameter and containing Tc-99m, to represent a small region in the stomach. Opposing images of the phantom were stored on magnetic disk with the 300-cc vial at distances from the camera increasing by 2-cm increments. This experiment was also repeated using In-111.

Phantom (c) explored the effects of meal volume, using the same water bath as for Phantom (b) but with vials of different volume at its center; 1 cc (1 cm diameter), 200 cc (5.6 cm diameter), 500 cc (6.7 cm diameter) and 1000 cc (10 cm diameter). Opposed images were made with Tc-99m and In-111, and stored on magnetic tape. For processing, a light pen marked off regions of interest. Decay corrections were applied as needed.

Human studies. Informed consent was obtained from ten healthy male subjects. In-111 DTPA was used as a liquid-phase tracer and mixed with the beverage to be ingested during the meal. The solid-phase tracer, chicken liver labeled with Tc-99m sulfur colloid, was fried and mixed with the solid food. All ten subjects ate a self-selected meal of meats, seafoods, fruits, vegetables, soup, salad, desserts, and beverages including wine. Quantities were not restricted; mean meal weight was 1692 g. Eight of the subjects were also given standardized meals of 900 g[†] and 300 g[‡] to evaluate the effect of meal size on gastric emptying. To minimize interference between the two tracers, $\nless$600 μCi of Tc-99m-labeled liver, or $\ngtr$100 μCi of In-111 DTPA, was given with each meal.

Scintigrams were made with a 410 keV diverging collimator, with 20% window centered over 140 or 247 keV as indicated. With the subject standing, 40-sec anterior and posterior images of the abdomen were obtained for each tracer, at 30-min intervals until >50% solid-phase emptying had occurred. An external Tc-99m point source was taped to the abdomen to allow accurate horizontal and vertical repositioning of the subject between images. All images were stored by computer on a magnetic disk for data processing.

TABLE 1. SOLID-PHASE HALF-EMPTYING TIME ± s.e.m.

Meal size (g)	Time (min) Geometric-mean data	Time (min) Anterior data	Percent difference
300	77 ± 5	85 ± 5	10.3
900	146 ± 26	196 ± 37	34.2
1692	277 ± 44	329 ± 75	18.7

A light pen was used to outline the whole stomach, or only its body or antrum as required. Regression analysis of the decay-corrected counts was used to calculate the time from mid-meal to half-emptying for the solid and liquid phases.

RESULTS

Labeling stability. The counting of the supernatants and residues from the in vitro labeling gave an average of 96.4% of the Tc-99m in the solid form with the lowest measurement (94.0%) at 5 hr. The count for the In-111 DTPA gave an average of 98.2% of the activity as liquid. The Tc-99m-labeled liver with water and gastric juice, with no mechanical mixing, showed 98.2% of the Tc-99m bound to the liver.

Phantom a. With geometric-mean correction, the point-source sensitivity for Tc-99m was ±1.9% for depths between 5 and 20 cm; it was 3.3% below the mean at 2.54 and 22.86 cm (Fig. 1). For In-111 it was within ±2.2% of uniform.

Phantom b. At any depth > 2 cm, the geometric-mean count rates from the 300-cc vial were constant within ±1.31%; at the two extremes the rate was 2.8% below mean. The graphs almost duplicate those in Fig. 1.

Phantom c. Under geometric-mean correction, the four volumes gave count rates within 0.2%.

In summary, the three phantoms gave corrected count rates that were independent of depth and volume as long as the depth was 2.5 cm or more.

Human studies. Data from each volunteer subject were corrected for radioactive decay and normalized to 100% for the counts at midmeal (time zero) for the total stomach counts. Table 1 lists the average half-emptying times for the solid-phase component of the meals, for both the geometric-mean and anterior-only data. The average liquid-phase, half-emptying times (Table 2) were shorter than the corresponding solid-phase components.

TABLE 2. LIQUID-PHASE HALF-EMPTYING TIME ± s.e.m.

Meal size (g)	Time (min) Geometric-mean data	Time (min) Anterior data	Percent difference
300	38 ± 4	41 ± 5	7.9
900	81 ± 12	86 ± 12	6.1
1692	178 ± 22	205 ± 44	15.1

DISCUSSION

Labeling stability. Technetium-99m-labeled chicken liver showed excellent stability as a solid-food marker in the presence of gastric juice. The increased percentage of Tc-99m in the liquid after the mixing in a blender was presumably due to the violent breakdown of the liver cells. In-111 DTPA, when used with proper ratio of radioactivity, can be used simultaneously with Tc-99m, without appreciable transfer to the solid food.

Phantom studies. Our phantom studies agree with the 2% variation reported by Ferrant and Cauwe (*8*). Geometric-mean correction for variations of source volume and depth minimizes the errors found in a single-view measurement.

The decrease in sensitivity with source positions close to the camera is presumably due to the very coarse resolution of the collimator (*9*). It has round holes 4.75 mm in diameter, 7.6 cm long, separated by septa ~1.58 mm thick. Nevertheless, the phantom studies validate the application of geometric-mean correction for measurements of the activity in a distribution that may change in volume and position.

Human studies. In 21 of the 26 gastric-emptying studies the anterior-only technetium counts were found to increase (average 13%) with time after conclusion of the meal. Increased counts were observed for 0.5 hr to as long as 2 hr in different subjects. The increase ranged from 2 to 39% for the individual studies and was seen in all ten subjects for the large meals. It was also seen in six of eight subjects for the 900-g meals, and in five of eight subjects for the 300-g meals.

In contrast, when the counts were corrected by geometric mean, only one subject gave increasing Tc-99m count rates. This subject ingested the greatest volume; he also showed an increasing anterior In-111 count, which no one else did. The increase in anterior Tc-99m counts for the 21 studies is due to the slight movement of the radioactivity from the posterior to anterior portion of the stomach body, and perhaps to some movement from the body of the stomach into the antrum. This increase in anterior counts was not prevalent in the indium data because of the smaller attenuation coefficient for the 247-keV energy and slightly faster emptying time for liquids. In the tissue-equivalent polystyrene phantom, a 2.54-cm movement of the source from the center of the phantom toward the anterior camera position caused a 35% increase in the anterior count (Fig. 1). This phantom study, along with the observed increase in anterior-only counts in our subjects, demonstrate the importance of applying the geometric-mean correction to human studies.

Previous reports of solid-phase emptying by Heading et al. (*4*) and MacGregor et al. (*2*) gave half-emptying times of 120 min for 185-g and 107 min for 425-g meals. Meyer et al. (*1*) found solid-food half-emptying times of 170 min for 850 g and 80 min for 425 g in one subject. Our study in ten subjects gave mean half-emptying times of 77, 146, and 277 min for meals of 300, 900, and 1692 g, respectively.

The percent differences in the average half-emptying times for the anterior against geometric-mean data are given in Tables 1 and 2 for each meal size. The anterior data alone consistently overestimate the half-emptying time. Tothill et al. (*5*), have previously described the underestimation of emptying rates for anterior data alone, which would produce an overestimation of the emptying time. In the individual studies, the differences between anterior and geometric-mean data ranged from −41% to +117% for Tc-99m data and from −32% to +95% for In-111 data. The largest variations between anterior and geometric-mean data for half-emptying time occurred with the larger meals and, as expected, the lower emitted energy.

Summarizing, the phantom studies have demonstrated the use of the geometric-mean correction for counting both Tc-99m and In-111. The results have been applied to human subjects to assess more accurately the rate of gastric emptying of both solid and liquid foods. The effect of various meal sizes has been studied using the geometric-mean method. This procedure offers an accurate quantitative index of gastric emptying rates, which can be useful in studying gastric physiology as well as a variety of disease states.

FOOTNOTES

[†] 200 g beef stew, 200 g applesauce, 50 g bread, 225 g of fresh orange juice, and 225 g of whole milk.

[‡] 150 g beef stew and 150 g of fresh orange juice.

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