DIAGNOSTIC NUCLEAR MEDICINE

Validation of Corrections for Errors in Collimation During Measurement of Gastric Emptying of Nuclide-Labeled Meals

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The study was undertaken to validate phantom-derived corrections for errors in collimation due to septal penetration or scatter, which vary wih the size of the gastric region of interest (ROI). Six volunteers received 495 ml of 20% glucose labeled with both In-113m DTPA and Tc-99m DTPA. Gastric emptying of each nuclide was monitored by gamma camera as well as by periodic removal and reinstillation of the meal through a gastric tube. Serial aspirates from the gastric tube confirmed parallel emptying of In-113m and Tc-99m, but analyses of gamma-camera data yielded parallel emptying only when adequate corrections were made for errors in collimation. Analyses of ratios of gastric counts from anterior to posterior, as well as analyses of peak-to-scatter ratios, revealed only small, insignificant anteroposterior movement of the tracers within the stomach during emptying. Accordingly, there was no significant improvement in the camera data when corrections were made for attenuation with intragastric depth.

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The gamma camera has been used increasingly in recent years to measure gastric emptying of nuclide-labeled test meals, both for research and clinical studies. The major advantages of this method are that it is non-invasive and that it is capable of tracking phase-specific food labels. With the recent knowledge that clinical disorders may affect gastric emptying of solid differently from liquid phases of the meal (*1*,*2*), many investigators are now measuring simultaneously gastric emptying of solid and liquid phases marked by separate, phase-specific nuclides with different energies.

Nevertheless, the use of the gamma camera for this purpose remains controversial because few studies have validated accuracy in tracking even one nuclide. Three potential sources of error have been recognized, but their magnitudes are debated. These are (a) overlap of the stomach over the duodenum, so that duodenal activity is counted inappropriately as gastric; (b) scatter from adjacent gut radiation into the gastric area; and (c) anteroposterior movement of nuclide within the stomach, with attendant variation in extinction. With the simultaneous counting of two nuclides, another potential source of error is variations in corrections for downscatter.

In a recent study (*3*), we found that corrections for downscatter varied with the size of the region of interest in phantom studies. In addition, studies with phantoms indicated an error in collimation related to the size of the region of interest and the energy of the nuclide, an error we suggested might be due to septal penetration and/or scatter. These two area-dependent errors might affect results in a complex fashion, since the size of the gastric region of interest (ROI) varies among subjects and almost always within subjects during the course of gastric emptying of the meal. The present study with liquid test meals was undertaken primarily to document these area-dependent errors and to validate in human subjects the methods of correction derived from phantom studies. Emptying data from external gamma counting were compared with those from analysis of aspirated gastric

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contents. In the course of this validation, additional information was provided about the magnitude of possible errors from overlap, scatter, and anteroposterior movement.

METHODS

Experimental procedure. *Single glucose meal.* After giving informed consent, six fasting, normal volunteers were intubated with a naso- or oro-gastric tube (o.d. = 0.5 cm; i.d. = 0.35 cm), which was positioned in the stomach by trial until it was situated so that more than 90% of a volume of water instilled could be recovered by aspiration on repeated testing over 30 min before the test (*4*). During the test, the tube was used for instillations and withdrawals of the liquid meal with a high-speed (180 ml/min) peristaltic pump; between instillations we used a 60-ml catheter syringe to wash the stomach through the tube.

The instilled liquid meal was 495 ml of 20% (w/v) glucose in water. The meal was labeled with three markers; (a) In-113m (b) Tc-99m and (c) a nonradioactive compound, polyethylene glycol 4000 (PEG). Both nuclide markers were chelated with DTPA and the meal contained about 1 mCi of each nuclide at preparation.

For 2–3 hr after initial instillation, gastric emptying of the meal was monitored by a two-channel gamma camera, interfaced to a computer and fitted with a 400-keV parallel-hole collimator. Subjects remained seated between counts but stood in front of the collimator for counts taken every 5 min during the first 30 min of the test, and every 10 min thereafter (time 0 = start of instillation). Subjects were counted three times at each interval: (a) first, an anterior count with one window set for the primary peak of In-113m and the other for that of Tc-99m; (b) then an anterior count with each window set respectively for scatter from In-113m and Tc-99m; and (c) finally a posterior count with windows set for peak activity from In-113m and Tc-99m. For the first 30 min of the test, counts were acquired over 30 sec; later all counts ran for one minute. Data were stored for subsequent analysis.

Beginning at 33 min, and at 30-min intervals thereafter, the stomach contents were pumped quickly from the stomach into a beaker and a 3-ml sample was saved for later analysis. As soon as the stomach was emptied, the gastric tube was disconnected from the pump and flushed with 50 ml of water with a 60 cc catheter syringe. Over the next minute, the 50-ml water rinse was repeatedly withdrawn into the syringe and reinstilled as rapidly as possible to equilibrate the rinse with residual gastric contents. At the end of that minute, the rinse was removed and saved for subsequent analysis. Stomach contents that had been removed before the rinsing procedure were then pumped back into the stomach, and counting of gastric activity with the gamma camera was resumed at the next and subsequent postcibal 10-min intervals. The entire cycle of aspiration, rinse, and reinstillation took about 4 min. Content of gastric markers calculated from subsequent analyses of aspirates and rinses (see below) were placed at midpoint in the time of the aspirate-rinse interval.

Sequential 20% glucose Tc-99m and glucose In-133m meals. The second part of this study was a variation on the first. At time zero we instilled 495 ml of 20% glucose marked only with Tc-99m DTPA. Counting with the gamma camera was performed as above except that only anterior photopeak gastric counts were recorded. Aspiration and rinse was done as described above, but only at 63 and 123 min. Following the 63-min procedure, residual Tc-99m in the rinsed stomach was counted with the gamma camera and expressed as percent of maximal total matrix counts. Then an additional meal of 495 ml of 20% glucose containing In-113m DTPA was instilled to replace the removed meal. For the next 60 min, gastric emptying of the In-113m was followed by counting photopeak gastric activity anteriorly with the gamma camera. Every 5 min during this second hour, gastric contents were rapidly swirled in and out of the stomach over a 1-min interval by repeatedly withdrawing and reinstilling 60-ml volumes with a catheter syringe connected to the gastric tube. At each cycle about 3 ml of the final syringe volume was retained for analysis.

Analysis of gamma-camera data. Acquired data were stored on disc and analyzed subsequently. All counts were back-corrected for nuclear decay to time zero. Beyond this process, the data were handled in three ways. With the *conventional method* the technician drew a region of interest (ROI) with a light pen around the stomach. Counts in the gastric ROI were then determined and expressed arbitrarily as a percentage of the highest total matrix count from the whole field in the first 30 postcibal min. Constant corrections were made for downscatter from the In-113m into the Tc-99m window; these corrections were 0.74 for the total matrix and 0.39 for the gastric ROI, as determined in previous phantom studies (*3*). This method, using operator-drawn ROIs and fixed corrections for downscatter, is the one commonly used by most investigators (*5*).

The second approach used a *calculator correction.* As with the conventional method, the technician drew the ROI around the stomach. However, this method differed from the conventional method by involving corrections for downscatter and for septal penetration that varied with the number of pixels in the gastric ROI. The curvilinear relationship between the magnitude of the corrections and the size of the gastric ROI had been determined previously in phantom studies (*3*), in which we found these corrections graphically. In the present study we found that the empirically derived curves could be fitted well to logarithmic functions.

Crosstalk In-113m to Tc-99m for ROI:

$$y = -0.0456 + 0.1046 \ln x, \quad r^2 = 0.93; \quad (1)$$

Septal penetration for In-113m ROI:

$$y = 0.0010 + 0.1250 \ln x, \quad r^2 = 0.97; \quad (2)$$

Scatter for Tc-99m ROI:

$$y = 0.694 + 0.0408 \ln x, \quad r^2 = 0.96; \quad (3)$$

where y = correction factor; x = number of pixels in the ROI; r^2 = correlation coefficient. Using these equations to calculate the three correction factors, we found a very close correspondence with graphical values. Consequently, a simple program was developed for a programmable calculator to correct for downscatter and septal penetration by means of the three above equations when the number of pixels and the counts in the ROI and in total matrix were entered into the program.

The third analysis used *computer corrections*, as detailed elsewhere (*6*). An edge-finding program was used to define the gastric ROI. A series of phantom studies was conducted to provide data from which the computer could estimate the depth of each nuclide independently by analyzing peak-to-scatter (P:S) ratios at each count. Once depth was determined, the computer program corrected for septal penetration, scatter, and downscatter as a function of both the area of the ROI and the depth of the nuclide (*6*). A final correction of the counts in the gastric ROI was then made to correct for changes in attenuation from anteroposterior movement of the nuclides during the process of gastric emptying. As with the conventional method and the calculator-corrected method, the corrected counts within the gastric ROI were normalized by expressing them as a percentage of the maximum total matrix counts in the first 30 min, these also being corrected for decay and attenuation with depth.

Posterior counts acquired from each subject were analyzed exactly as described for anteriorly acquired counts, and the conventional and the calculator-corrected methods were applied. Geometric means at each counting period were determined from the percentage of total counts in the posterior gastric ROI and the percentage of total counts in the anterior gastric ROI with primary-peak windows using anterior and posterior data acquired within 3 min of each other. Arbitrarily the geometric mean so derived was plotted as of the time of the anterior photopeak counting. The ratio of counts of each nuclide in the anterior gastric ROI to counts in the posterior ROI (A:P ratio) was calculated to determine the depth of the nuclide. Details of this method are presented in a companion study (*6*).

Analyses of gastric aspirates and rinses. One-ml samples of gastric aspirates and rinses were analyzed for PEG and counted for In-113m and Tc-99m in a well counter. In the first part of the study, the In-113m was counted 3–4 half-lives from the start of the meal when the Tc-99m had decayed less than 2 half-lives. Since the meal initially contained 1 μCi/ml of each nuclide, the very high (about 0.4 μCi/ml) activity of the Tc-99m flooded the detecting crystal. The problem was solved by hand-counting each sample in a counting tube surrounded by a 1-mm lead envelope. Preliminary studies had shown the lead blocked out essentially all Tc-99m activity but allowed the In-113m activity (393 keV) to penetrate and be counted with virtually no loss. Technetium-99m was counted with a conventional well counter on the day after the initial In-113m counting, when the Tc-99m had decayed by 5–6 half-lives and the In-113 m was essentially dead.

In the second part of the study, with sequential meals containing first Tc-99m and then In-113m, the Tc-99m in the samples of the In-113m meal was very much lower in activity, since it represented residue after aspiration of the first meal. Therefore, the two nuclides could be counted concurrently in a two-channel well counter, using appropriate corrections for crosstalk.

Gastric content of each of the three markers was computed from their concentrations in the aspirates and rinses. Thus, the amount removed in an aspirate was:

$$\text{Amt aspt} = V_{asp} \times M_{asp} \quad (4)$$

where V_{asp} = the volume (ml) and M_{asp} = the concentration (amt/ml) of the marker. The residual amount of marker left in the stomach after aspiration was determined after calculating the residual volume.

$$V_r \times M_{asp} = (V_r + 50) \times M_{rin} \quad (5)$$

where M_{asp} was the measured concentration of the marker in the aspirate, M_{rin} was the final measured concentration of the marker in the rinse, and 50 was the volume of the rinse. After solving Eq. 5 for V_r (ml), we could calculate gastric content of the marker:

$$\text{Gastric content} = \text{Amt Asp} + (V_r \times M_{asp}) \quad (6)$$

The gastric content as determined by Eq. 6 was then normalized to the percentage of the amount in the meal (the product of the meal concentration of the marker and the meal volume, 495 ml). This value was compared directly with the percentage of nuclide remaining in the stomach as determined by the gamma camera.

RESULTS

20% glucose meal labeled with Tc-99m and In-113m. The concentrations of the three markers in the serial gastric aspirates declined in parallel, so that the ratio of one marker concentration to the other remained constant throughout the entire time course of gastric emptying. Data for PEG are not shown, but Figs. 1–3 and Tables 1 and 2 show calculated gastric content of Tc-99m DTPA and In-113m DTPA at the sampling times.

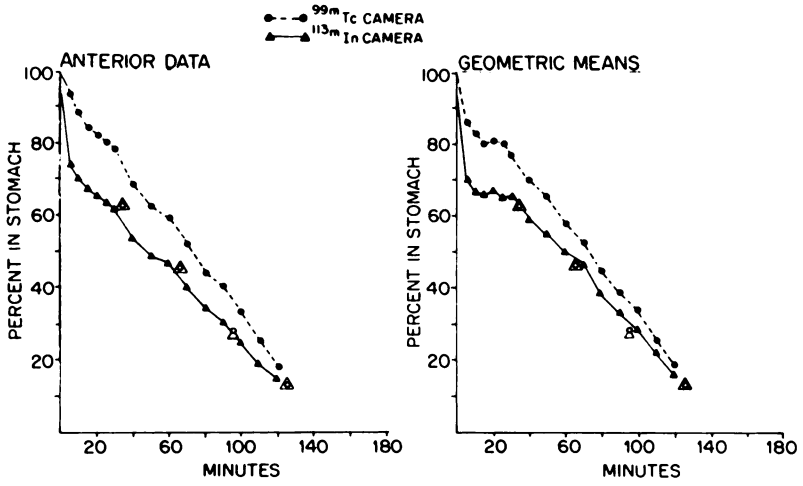

FIG. 1. Percent of gamma activity in gastric ROI against time after 495-ml drink of 20% glucose containing both In-113m and Tc-99m DTPA. Camera data for In are shown as solid triangles, and for Tc as solid circles. Percent of each nuclide remaining in stomach was independently determined by aspiration through gastric tube (hollow triangles for In and hollow circles for Tc). Left-hand graph gives time courses calculated from anterior counts after conventional corrections; at right are from geometric means of anterior and posterior gastric ROI counts for each nuclide after conventional corrections. Although aspirates indicate parallel emptying of the two nuclides, camera data misrepresent In-113m as having more rapid initial emptying than Tc-99m (or a more negative starting index), an error not corrected by use of the geometric mean.

Analyses of the aspirates and rinses thus confirmed that the two nuclides emptied in parallel.

By contrast, when data from the gamma camera were computed by conventional methods, the gastric emptying of the In-113m was not found to parallel emptying of the Tc-99m: the indium appeared to empty initially faster than the technetium (Fig. 1).

The use of a geometric mean of anterior and posterior gastric counts did not correct the nonparallel emptying of the two nuclides (Fig. 1). Some difficulty was encountered in obtaining posterior counts. After 20 min, there was so much scatter in Subject 4 that the posterior gastric region of interest could no longer be defined. Similarly, there was difficulty in defining this region after 40 min in Subject 5, and after 100 min in most of the other subjects.

When calculator corrections were applied for septal penetration and downscatter, the computed emptying of the In-113m paralleled that of Tc-99m, and the two curves agreed closely (Fig. 2). The agreement after calculator corrections resulted mostly from the upward correction of the In-113m curve. The calculator-corrected geometric means of anterior and posterior area contents described curves for each nuclide only slightly below the calculator-corrected anterior curves (Fig. 2).

The computer-corrected curves (Fig. 3) were quite similar to the anterior, calculator-corrected curves, both showing virtually identical emptying of the In-113m and Tc-99m. When computer analyses of either P:S ratios or A:P ratios were used to calculate the depth of the nuclides from the collimator, no consistent anteroposterior movement was detected for the first 100 postcibal minutes (Fig. 4). However, calculated depth of the Tc-99m from the collimator was more than that for the In-113m when the P:S method was used, but not with A:P, and the P:S method placed the In-113m anterior to the position calculated from the A:P ratios. After 100 min, there was increasing difficulty in analyzing the P:S ratios because of the low count rate in the gastric region and thus proportionally more scatter of radiation from adjacent gut into the gastric ROI. This problem was so

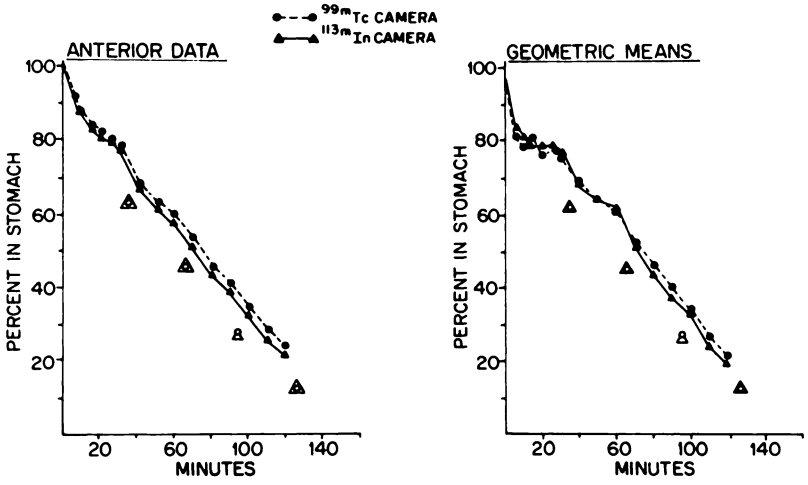

FIG. 2. Same notations as in Fig. 1. Here camera data were corrected by calculator for errors in collimation due to septal penetration and scatter (see text). These corrections eliminated discrepancies between time courses of the two nuclides, whether or not geometric means were used. In both this and Fig. 1, geometric means are averages from six subjects through 20 min but of only five thereafter because posterior gastric ROI could not be defined after 20 min in Subject 4. Geometric means after 40 min in Subject 5 were only approximate because of similar difficulty.

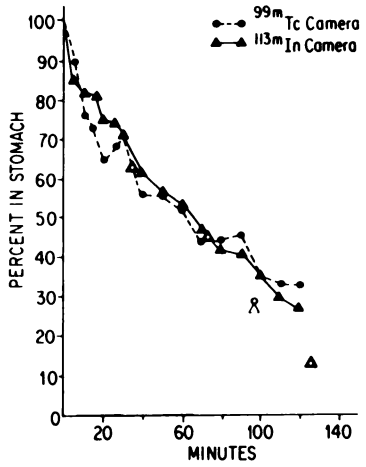

FIG. 3. Camera data collected anteriorly and corrected for changes in depth by P:S ratio. Same notation as in Fig. 1. Curves resemble those in Fig. 2 except for upward turn in last 20 min due to over correction by P:S method suggesting posterior movement (see text and Fig. 4). Values are averages from six subjects through 70 min but from only five from 80 min on because of nonsensical indicated depths for Tc-99m in Subject 5.

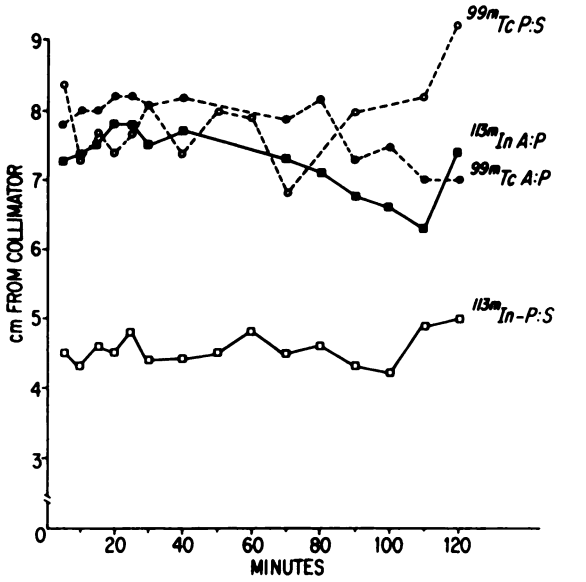

FIG. 4. Distance (cm) from collimator to In-113m and Tc-99m tracers, as determined from ratios of photopeak anterior and posterior ROI counts (A:P, solid points) and from peak-to-scatter ratios from anterior counts within gastric ROI (P:S, hollow points). Because of difficulties in defining posterior ROIs in two subjects, A:P data are averages from six subjects through 20 min, five subjects from 20–40 min, and four from 40 min on. P:S curves depict average detected depths in six subjects through 70 min, but in only five from 80 min on because of nonsensical values in Subject 5 (see text). Neither method showed significant anterior movement in first postcibal hour, but A:P method showed gradual movement forward during last hour, while P:S method showed posterior movement in last 20 min. P:S method did not place the two nuclides at same depth in this study.

severe in Subject 5 from 90 min on that calculated depths for Tc-99m were nonsensical: the indicated depth approached total body thickness. The problem accounted for an apparent posterior movement of the nuclides.

All emptying curves were fitted by a least-squares linear to the linearized exponential:

$$\ln Y = -kt + \ln B, \qquad (7)$$

where Y = percentage of gastric counts in the stomach, t = postcibal minutes, and k the rate constant for gastric emptying. A starting index, S.I. (min), was calculated by solving for t, when Y was set at 100%. This method of expression is commonly used for liquid test meals (*7,8*). Half-emptying time was calculated from 0.693/k plus the starting index. Regardless of the corrections applied, emptying data from each subject (except one with Tc-99m) fitted the logarithmic function well. Values for k were similar (Table 1), indicating that the general shapes of the exponential time courses were similar no matter which correction was used. Steep initial emptying (*Y* intercept considerably below 100%, negative starting index) was pronounced for In-113m unless area-related corrections were applied for septal penetration or scatter, either by calculator or computer. Without such corrections, both the starting index and the 50% emptying times for In-113m differed significantly from corresponding values for Tc-99m, even though aspiration data revealed virtually identical values for the same parameters between the two nuclides (Table 1). These discrepancies were not corrected by the geometric mean of anterior and posterior counts if area corrections were not applied (i.e., geometric-conventional). Area-corrected geometric means gave the greatest consistency between values for In-113m and Tc-99m, but discrepancies between corresponding parameters for the two tracers did not differ significantly whenever any form of area correction was made. All corrections of gamma-camera data produced lower values for k and longer half-emptying times than did the data from the aspirates (Tables 1 and 2).

With each method of analysis, gamma-camera data were (linearly) interpolated so as to obtain the percentages of meal counts in the gastric ROI at the same time as the percentage of meal counts in the stomach as determined by gastric aspiration (Table 2). This method of analysis allowed a direct comparison between camera and aspirate data without fitting of the data to any model. While there was incomplete consistency, the general result of these comparisons (Table 2) indicated higher values from camera-derived data than from analyses of the aspirates. Whenever area corrections were not made, camera values from In-113 did not differ from corresponding values from aspirates. Computer-corrected camera values for both In-113m and Tc-99m also did not differ from values of aspirates at the 35-min sampling, but at later sampling times differences between computer-corrected camera values and aspirate values did emerge. The general tendency for camera

TABLE 1. PARAMETERS* OF GASTRIC EMPTYING AFTER VARIOUS CORRECTIONS OF GAMMA-CAMERA DATA (MEANS ± s.e.)

Correction	Nuclide	k	S.I.*	50% Emptying
Anterior-conventional	In-113m	0.014 ± 0.001	−8.2 ± 3.2†	44.6 ± 3.7†
	Tc-99m	0.013 ± 0.002	+3.8 ± 2.4	59.8 ± 5.4
Geometric-conventional	In-113m	0.013 ± 0.001	−10.2 ± 3.4†	44.7 ± 2.8†
	Tc-99m	0.013 ± 0.001	+2.2 ± 3.3	58.1 ± 4.0
Anterior-calculator	In-113m	0.013 ± 0.001	+4.2 ± 4.2	61.9 ± 5.8
	Tc-99m	0.013 ± 0.001	+7.3 ± 3.4	52.7 ± 10.5
Geometric-calculator	In-113m	0.013 ± 0.001	+0.4 ± 3.6	57.7 ± 5.6
	Tc-99m	0.012 ± 0.002	−3.8 ± 5.2	60.1 ± 6.6
Anterior-computer	In-133m	0.011 ± 0.002	−5.2 ± 4.0	49.8 ± 11.7
	Tc-99m	0.010 ± 0.002	−12.4 ± 12.4	65.1 ± 11.1
Aspiration‡	In-113m	0.015 ± 0.001	+3.5 ± 0.9	51.8 ± 3.7
	Tc-99m	0.016 ± 0.002	+5.6 ± 1.3	51.0 ± 4.2

* Data from each of six subjects were fitted to ln Y = −kt + ln B, where Y = % emptied and B = % in stomach when t = 0. The starting index (S.I.) was calculated in each case by setting Y = 100 and solving for t (min). 50% emptying was calculated from (0.693/k) + S.I.

† $p < 0.05$ vs. corresponding value for Tc-99m, paired t-test.

‡ Values derived from analyses of gastric aspirates, independent of gamma-camera measurement. Since data were collected less often than with gamma camera, direct comparisons of parameters cannot be made; and aspiration data are presented only as a guide.

values to be higher than aspirate values paralleled the lower k values and longer 50% emptying times noted when all data along the time courses were fitted to exponential regressions (Table 1).

Three possibilities might explain these differences between the camera and aspirates: (a) the camera data were in error, giving too high an estimate for gastric content; (b) the aspirates gave values too low; or (c) both suffered error.

Sequential meals of 20% glucose. The possibility of error from the gamma camera might depend on scatter or overlap of gut activity into the gastric region, giving an erroneously high estimate of gastric content. Failure to mix the rinse with residual volume might result in a low estimate of M_{rin} and hence of V_r (see Eqs. 5 and 6); this error would lead to an underestimate of gastric content by the aspiration method. Subjects 1, 2, and 6 from the first study were restudied along with three

TABLE 2. GASTRIC CONTENT OF NUCLIDES AFTER A DOUBLE-LABELED GLUCOSE MEAL, DETERMINED BY ASPIRATION AND BY GAMMA CAMERA, WITH VARIOUS CORRECTIONS

Indium-113m	35 min	65 min	95 min	126 min†	50% emptied‡
Aspiration	63 ± 3	46 ± 4	27 ± 5	15 ± 2	51 ± 4
Conventional corrections	59 ± 3	44 ± 7	28 ± 5	16 ± 4	50 ± 5
Calculator corr	72 ± 4*	55 ± 4*	36 ± 5*	21 ± 9	63 ± 8*
Computer corr	66 ± 4	51 ± 6*	35 ± 4*	24 ± 4*	61 ± 6*
Technetium-99m					
Aspiration:	63 ± 3	46 ± 4	28 ± 4	13 ± 3	51 ± 4
Conventional corr	74 ± 4*	56 ± 4*	37 ± 6*	17 ± 5	63 ± 7*
Calculator corr	73 ± 4*	57 ± 4*	39 ± 6*	19 ± 4*	65 ± 7*
Computer corr	64 ± 6	48 ± 4*	40 ± 4†	—†	66 ± 9

* $p < 0.05$ vs. aspiration value, paired t-test.

† Only five of the six subjects compared because data from Subject 5 became nonsensical beyond 100 min (see text) for In-113 m, and beyond 80 min for Tc-99m, due to low absolute counts in the stomach (see text).

‡ Time in minutes calculated as in Table 1 from ln Y −kt + ln B using (interpolated) points at times 0, 35, 65, 95, and 126 min for data from camera and aspirates.

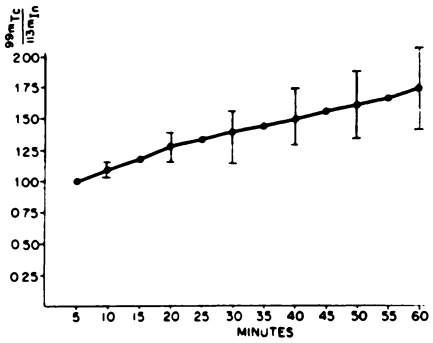

FIG. 5. Increasing ratio of residual Tc-99m to In-113m in aspirates obtained every 5 min after instillation of 20% glucose meal free of Tc-99m but containing In-113m DTPA (see text). 100% was defined arbitrarily as ratio in first aspirate after instillation of the In meal (that is, at 5 min). Upward shift in ratio with time indicates that Tc-99m in the prior meal took more than just a few minutes to equilibrate with rinses or with second meal.

additional subjects (Nos. 7, 8 and 9). These six subjects were given two successive meals of 495 ml of 20% glucose, the first marked with Tc-99m DTPA and the second with In-113m DTPA, as described above. The primary goal of this second experiment was to determine to what extent the rinses at 60 min equilibrated with residual gastric contents.

After the first Tc-99m-labeled meal was aspirated and the stomach rinsed, it was replaced with the second meal marked with In-113m. Every 5 min for the next hour, gastric contents were mixed by rapid withdrawal and reinstillation of 60-ml volumes. The ratio of concentration of Tc-99m to In-113m was determined by counting 1-ml samples of gastric contents taken every 5 min during the second hour. In all six subjects, these ratios increased significantly with time. In three subjects (Nos. 2, 6, and 7), the ratios reached a maximum value after 45, 50, and 20 min respectively. In the other three subjects, the ratios kept increasing throughout the entire second hour. The mean increase for all six subjects was 73% by the end of the second hour, indicating that 3-min equilibrium of rinse with residual volume had not been adequate (Fig. 5), since equilibration was not achieved over an entire hour in three subjects.

When the first meal had been removed and the stomach rinsed with 50 ml of water, residual gastric content of Tc-99m was calculated by subtracting the total amount of Tc-99m removed (the amount in the aspirated meal plus that removed in the rinse) from the total content calculated by Eq. 6 to have been in the stomach. The residual gastric content so calculated was compared with the residual content determined by standing the patient in front of the gamma camera and counting residual Tc-99m in the emptied and rinsed stomach (Table 3). With each of the six subjects, the gamma camera showed the emptied stomach to be clearly outlined with Tc-99m activity (Fig. 6), and in each case the residual activity indicated by the camera was several orders of magnitude above that calculated from the aspirates and rinses.

The second glucose-In-113m meal was then instilled, and the rate of gastric emptying of the In-113m followed by the gamma camera. At the end of the second hour, intragastric volume (V_g) was calculated:

$$V_g = f\,(495\ I_0)/I_g, \qquad (8)$$

where f = the fraction of ingested In-113m left in the stomach at the end of the second hour, as determined by

TABLE 3. GASTRIC CONTENT OF Tc-99m AFTER EMPTYING THE STOMACH OF THE GLUCOSE MEAL LABELED WITH Tc-99m DTPA

Subject	Ratio*	Residual content†	Camera content‡	Recalculated residual§
No. 1	2.45	0.1%	3.9%	4.0%
2	1.15	1.4%	15.9%	12.7%
6	1.17	1.8%	14.9%	10.7%
7	1.06	5.7%	14.5%	10.2%
8	2.99	0.5%	3.1%	4.9%
9	1.60	5.2%	6.9%	6.3%
mean ±	1.74 ±	2.5 ±	9.9 ±	8.1 ±
s.e.	0.33	0.9%	2.4%	1.5%

* Expresses $(Tc/In)_{60\ min} \div (Tc/In)_{5\ min}$, see text.

† Determined by the total content minus the amount of nuclide removed in the aspirate and the wash, and expressed as a percent of meal counts.

‡ Counts in the gastric area after the stomach was emptied and washed free of the Tc-99m-labeled meal; counts are expressed as a percent of total counts in the camera field after taking the meal (see text).

§ Recalculated from the derived gastric volume, the gastric concentration of Tc-99m, and the percent of In-113m emptied at 60 min after instilling the second glucose meal labeled with In-113m DTPA. Values are expressed as a percent of meal counts.

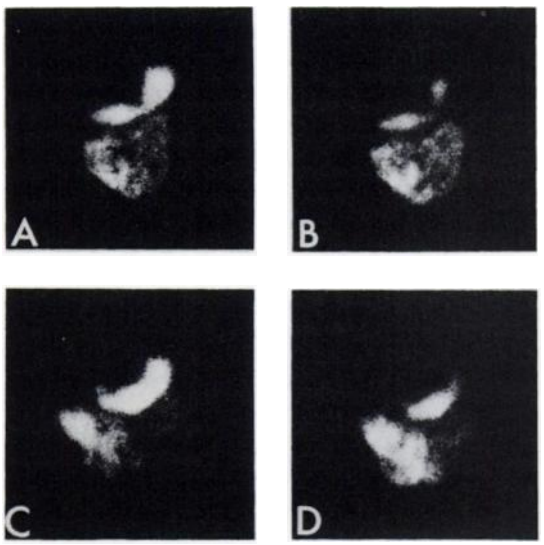

FIG. 6. Scintigrams (CRT) of Tc-99m in abdomen just before final evacuation of Tc-99m-containing meal (left side) and after removal of the meal and a water rinse (right side). Subject 2 (top) and Subject 6 (bottom), were counted by gamma camera to have had 15.9% and 14.9% of Tc–99m activity, respectively, remaining in emptied and rinsed stomach (see text). Note especially intense Tc-99m activity remaining in both fundus and antrum of subject 2, whereas subject had intense activity throughout stomach but especially in corpus. Even the other subjects, who had lower residual Tc-99m activity after emptying and rinsing the stomach, showed Tc-99m clearly outlined within gastric contours.

gamma camera; I_0 and I_g concentrations (cpm/ml) of indium respectively in the original meal and in the gastric content at the end of the second hour; and 495 was the volume (ml) of the meal. Assuming that residual Tc-99m emptied at the same rate as In-113m during the second meal, the gastric content of Tc-99m just before the instillation of the second meal could be recalculated as

$$\text{Amt} = V_g T_g / f, \qquad (9)$$

where V_g and f are as in Eq. 8, and T_g was the concentration (cpm/ml) of Tc-99m in the gastric contents at the end of the second hour. When residual gastric content of Tc-99m was recalculated in this fashion, the value corresponded closely to the camera estimate of residual content in the emptied stomach (Table 2), at the end of the first hour.

DISCUSSION

Three previous studies (*9–11*) have attempted to validate gastric scintigraphy as a means of measuring gastric emptying by comparing camera-derived emptying data for a liquid meal with those from analyses of gastric aspirates. In one of these studies, gastric contents were simply emptied, and no dilution indicators were applied to correct for unaspirated gastric residue (*9*). In all three studies, the gastric content of nuclide was compared (camera against aspiration value) at one point along the time course of gastric emptying. Overall accuracy was assessed by comparing these two values, and there were no attempts to discern which of the several potential sources of error might account for discrepancies.

The present design differed significantly from those used previously. First, comparisons between camera and aspiration data were made at several points during the course of gastric emptying so as to allow point-by-point, as well as overall, statistical comparisons. Second, two tracers with different energies were distributed in the same homogenous meal. It was assumed the two nuclides should follow the same time course of gastric emptying. The use of the two markers would therefore test the adequacy of previously determined corrections for downscatter and septal penetration. In addition, significant anteroposterior movement of nuclide might be revealed by the relative changes in percent of activity of one nuclide over the other in the gastric ROI, since posterior movement would attenuate much more heavily the lower-energy Tc-99m radiation (*13*).

Serial aspirates indeed confirmed that the two chelated nuclides emptied in parallel. Thus the Tc-to-In concentration ratio remained constant throughout the time course of gastric emptying (data not shown) and the gastric content calculated for each nuclide at the serial samplings confirmed parallel emptying (Figs. 1–3, Tables 1–2). The assumption in the design was thus experimentally verified, and two criteria could therefore be used to judge the accuracy of the gamma camera: (a) the time course of gastric emptying measured with the gamma camera should agree with that measured by the aspiration method, and (b) both nuclides should empty in parallel.

The second criterion was met only when corrections were made for septal penetration (Figs. 1–3, Table 1); otherwise the indium curve diverged from the technetium curve, especially early in the test. This was evident from the curves and the negative SIs for indium (Table 1, footnote), which differed significantly from those for technetium when these corrections were not applied. The divergent behavior of camera-derived curves of the two nuclides was not the result of anteroposterior movement, since correcting for such movement by using a geometric mean did not correct the divergence unless a correction for septal penetration was also applied, whether by calculator or computer. Furthermore, analyses of both A:P and P:S ratios failed to demonstrate significant anteroposterior movement in the first 100 postcibal minutes, when most of the discrepancy was noted (Fig. 4).

Two conclusions can be drawn from these observations. First, previously determined corrections for septal penetration [with the 400-keV collimator these pertain mostly to the In-113m (*3*)] appear to be accurate. Second, anteroposterior movement of the nuclides was insignificant. In his more recent paper, Tothill (*12*) also found that there was no consistent or significant ante-

roposterior movement when erect subjects were studied with a gamma camera after a liquid glucose meal.

Nevertheless, corrections for septal penetration mainly moved the indium curve upward to approximate the technetium curve. Area-related corrections for downscatter modified the technetium curves to a lesser degree. Even though these corrections nearly reconciled the two curves (Figs. 1-3), the major effect was to move the indium data further above the values calculated for gastric content by the aspiration-rinse method (Tables 1-2). On point-by-point comparisons, the corrected camera data were significantly above the aspiration data. Moreover, there were significant differences between 50% emptying times as computed from the corrected camera data and the aspirates (Table 2). Thus, corrections produced paradoxical effects with regard to the two criteria for adequacy: they brought values for the two nuclides closer together but raised values for In-113m so that the camera data then became systematically higher than the aspiration data.

All previous studies making comparisons between camera and aspirates reported similar discrepancies (*9–11*). Tothill (*13*) suggested the higher values from the camera might be due to anteroposterior movement. Clearly this explanation is not correct, since neither the geometric means nor computer corrections for depth removed the discrepancies (Tables 1-2). Delin (*10*) suggested that at least some of the differences were the result of scatter or overlap of gut activity into the gastric ROI.

The second phase of this study was undertaken to determine whether the aspiration-rinse method may have underestimated gastric content of nuclides. Unequivocally, there was incomplete equilibration between rinse and residual volumes as indicated by the steadily increasing ratios of Tc-99m to In-113m in gastric samples over 20–60 min after instillation of the In-113m meal (Fig. 5, Table 2). The problem probably resulted from inability to mix thoroughly the small rinse volumes in the dependent portion of the stomach with Tc-99m-marked fluid in the interstices of the gastric pits of both upper and lower stomach. Camera images of the emptied and rinsed stomachs (Fig. 6) showed residual Tc-99m activity spread throughout the stomach in all subjects. In any case, the demonstrated lack of equilibration, over as much as 60 min, of Tc-99m between residual portions of the indium meal—and even of its larger instilled volumes—confirmed a potentially significant underestimate by tube methods as the result of poor mixing.

To judge the magnitude of this underestimate, we compared recalculated residual technetium activity with camera estimates of the same. The method of recalculating this residual was described above by Eqs. 8 and 9. While the gamma camera itself was used to calculate f, the fractions of In-113m remaining in the stomach at the end of the second hour, f cancelled out when Eqs. 8 and 9 were combined. Thus, the only approximations involved in this calculation were the assumptions that residual Tc-99m emptied in parallel with In-113m, and that final equilibration of the residual Tc-99m into the In-113m meal was achieved by the time of the last sample. We know the last condition was met in Subjects 2, 6, and 7; it may have been met in the other three subjects, but could not be ascertained, as Tc-to-In ratios were still rising between the last two samples. Since technetium in the meal contents increased with time in all subjects, the first condition was never met, but only approximated. Nevertheless, the recalculations (Table 3), estimating a residual Tc-99m content after the first aspiration and rinse, came remarkably close to the camera estimate and were sometimes orders of magnitude above the earlier estimates based on the original aspiration-and-rinse method.

This last finding indicates that much of the discrepancy between estimates by camera and by aspiration methods resulted from underestimation by the latter and not from scatter or overlap of gut activity into the gastric ROI. Independent corroboration of this conclusion was provided by the camera images showing stomachs silhouetted by significant quantities of residual Tc-99m after the first aspiration and rinse (Fig. 6). If activity in the gastric ROI were due to scatter and overlap, instead of residual content, we would have expected much more diffuse activity in the region of the stomach rather than sharply demarcated activity confined within the gastric walls.

Adequacy of the P:S ratio method for computing depth of intragastric nuclides is documented and discussed in detail in a companion study (*6*). Like the A:P ratio method, the P:S did not detect significant anteroposterior shifts in the present study. Both methods proved to be not universally applicable. In two subjects A:P ratios could not be determined as early as 20 and 40 min after the meal because scatter was so intense on posterior imaging that the gastric ROI could not be defined. In one subject the P:S ratios produced nonsensical values for depth of the nuclides after 80 min. This problem was due largely to low activity within the nearly empty stomach (*6*). Also, in the present study, Tc-99m was indicated to be more posterior than In-113m by the P:S method (Fig. 4). Depths calculated for In-113m by the P:S method, and for both nuclides by the A:P method, were quite similar to those found in a companion study with doubly labeled chicken liver (*6*), so we believe that the more posterior location of the Tc-99m by P:S method in the present study is an anomaly. The ratio of Tc-to-In counts in the total matrix at the start of the present study averaged 2.9 ± 0.2, about one third of the ratio in the companion study (*6*). The relatively higher In-to-Tc activity might have worsened errors from downscatter, thus altering the absolute depths calculated from the P:S method. Despite this problem, the depth curves calcu-

lated by P:S for Tc-99m showed no significant movement, a fact confirmed by the other three curves (Fig. 4).

In summary, the present study indicates the gamma camera is an acceptable tool for measuring rates of gastric emptying of nuclide-labeled liquid meals. The findings suggest that errors from overlap and scatter of gut activity into the gastric ROI are small, and they confirm that there is no significant or consistent anteroposterior movement of nuclides, which might introduce errors from attenuation, with liquid meals in erect subjects. By contrast, errors previously ascribed to defects in collimation (i.e., septal penetration and scatter) may become significant if uncorrected, and phantom-derived corrections appear to be quite adequate in eliminating these errors. Like other studies, the present experiments have shown significant discrepancies between estimates of gastric content derived from camera studies and those derived by aspiration techniques, but current evidence is compelling that much of the discrepancy arises from defects in the aspiration method.

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