Error and Corrections with Scintigraphic Measurement of Gastric Emptying of Solid Foods

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Previous methods for correction of depth used geometric means of simultaneously obtained anterior and posterior counts. The present study compares this method with a new one that uses computations of depth based on peak-to-scatter (P:S) ratios. Six normal volunteers were fed a meal of beef stew, water, and chicken liver that had been labeled in vivo with both In-113m and Tc-99m. Gastric emptying was followed at short intervals with anterior counts of peak and scattered radiation for each nuclide, as well as posteriorly collected peak counts from the gastric ROI. Depth of the nuclides was estimated by the P:S method as well as the older method. Both gave similar results. Errors from septal penetration or scatter proved to be a significantly larger problem than errors from changes in depth.

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Using pieces of filter paper labeled with Tc-99m as a marker for solid food, Tothill (*1*,*2*) reported significant anterior movement of the Tc-99m during the course of gastric emptying of the marker. In both of his papers, anterior movement was detected by comparing counts of Tc-99m taken over the anterior and posterior body walls simultaneously. Tothill reported that movement of the labeled filter paper was more pronounced when patients were recumbent rather than erect; yet anterior movement was appreciable when subjects were studied while standing in front of a gamma camera (*2*). Because of decreasing attenuation of photons as the Tc-99m moved toward the detector, this anterior movement would create the false impression of slower gastric emptying than that which actually took place.

For several reasons we felt it would be desirable to confirm and extend Tothill's findings. First, we wondered whether the results with Tc-99m labeled chicken liver, a three-dimensional substance, might differ from those with Tc-99m paper. Second, we found in a companion study (*3*) that excessive scatter sometimes prevented precise identification of the stomach confines when subjects were counted posteriorly with a gamma camera. Further, our phantom data indicated an increase in septal penetration and scatter as the source-to-collimator distance increased on posterior scans. These problems might affect the accuracy of detecting and correcting anteroposterior movement by Tothill's method (*1*,*2*). Consequently, we sought an independent method for identifying and correcting this source of error. The method we chose uses peak-to-scatter (P:S) ratios as an index of depth. Finally, simultaneous or rapidly sequential counting over the abdomen and back is cumbersome and impractical; our alternative method requires only anterior counting and would be much more practical if it gave comparable results. Therefore, we chose to compare it directly with Tothill's method in a situation (with solid food) where significant anterior movement of gastric markers was expected.

METHODS

After giving informed consent, six healthy, fasting male volunteers consumed test meals consisting of 200 ml of water, 225 g of canned beef stew, and one cooked chicken liver (averaging 30 g). The chicken liver was labeled with both In-113m and Tc-99m. About 2 hr before each test, Tc-99m sulfur colloid was injected into

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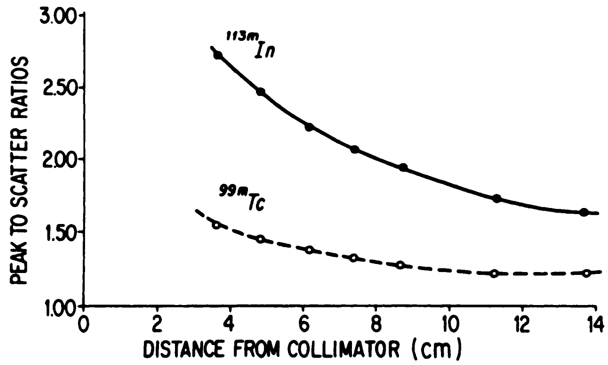

FIG. 1. Phantom study showing peak-to-scatter ratios with changing distance of source from collimator.

the wing vein of a live chicken. An hour later In-113m colloid was similarly injected into the same live chicken (*4*). The chicken was killed 30 min after the second injection, the liver removed, washed and cooked by enclosing it in a sealed boilable cooking bag and immersing the bag in boiling water for 20 min. After cooking, the liver was diced into 10-mm cubes and mixed thoroughly into the beef stew. Each liver contained about 0.4 mCi of In-113m and 2.0 mCi of Tc-99m. In vitro studies confirmed that the ratios of Tc-99m to In-113m were uniform throughout the entire mass of doubly labeled chicken liver.

The time courses of gastric emptying of the doubly labeled liver were followed with a gamma camera by collecting anterior peak, anterior scatter, and posterior peak counts as detailed elsewhere (*3*). Calculations were made in three ways: (a) Anterior and posterior peak counts were corrected for decay and downscatter by conventional methods (that is, for nuclear decay and downscatter of In-113m computed as a constant percentage of peak counts). (b) These counts were also corrected with a programmable calculator for size of the region of interest (ROI) (*3*). (c) A computer program was developed to correct for changes in distance of the nuclides from the collimator surface.

By measuring P:S ratios from counts collected anteriorly at each counting, the program computed the average depth of the nuclide. This computation was accomplished by reading the observed P:S ratio against an exponential curve derived from phantom studies. Using a 14 × 8 × 6 cm source containing In-113m and Tc-99m and immersed in a water bath, we determined how the P:S ratio varied as the source was moved away from the collimator surface by interposing an increasing thickness of Plexiglas sheets (Fig. 1). The projected size of this phantom (450 pixels) was similar to that of the stomach as seen during in vivo studies with the solid meal. The source itself was immersed in 23 cm of water in a tank above the Plexiglas to simulate scatter from body tissues around and behind the stomach. P:S ratios from these phantom studies, as well as from subsequent studies of gastric emptying, were determined by drawing a ROI so that the perimeter of the ROI closely approximated the bottom edge of the source, as seen on peak images, but widely circumscribed the remaining two thirds of the image boundaries. This maneuver provided consistent P:S ratios (within ±5% on repeated analyses), yet eliminated most scattered radiation from the gut below the stomach in the in vivo studies of gastric emptying.

Once depth was determined, the computer applied additional corrections for variations in In-113m downscatter and septal penetration or scatter with variations in the size of the ROI. In phantom studies similar to those described above, the ratio of activity within a ROI around a source to the activity from the total matrix varied not only with the size of the ROI at any one depth from the collimator surface, but also decreased for any fixed size of ROI, as the source was moved away from the collimator (Fig. 2). Similar variations were described with In-113m downscatter into the Tc-99m window. These complex variations with both depth and size of the ROI generated a three-parameter mathematical regression so that computer could calculate a suitable correction by fitting depth and size of ROI during emptying studies to this same mathematical function.

Depth-related corrections for attenuation, corrections for area effects, and depth-related adjustments of area corrections were applied to peak counts for each nuclide within the anterior gastric ROIs in studies of gastric emptying. Gastric ROIs were drawn by computer with an edge-finding routine. The percentage of nuclide remaining within the stomach was determined by dividing counts within the gastric ROI (after corrections for nuclear decay, area, and depth) by the maximum total

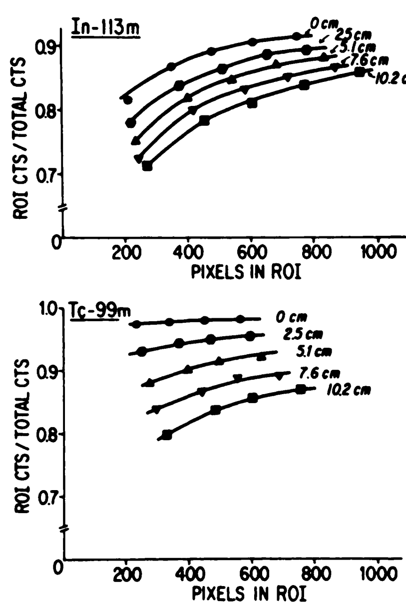

FIG. 2. Results from phantom studies with 400-keV parallel-hole collimator illustrating changing ratio of counts within ROI to total counts, with (a) size of ROI and (b) depth of source.

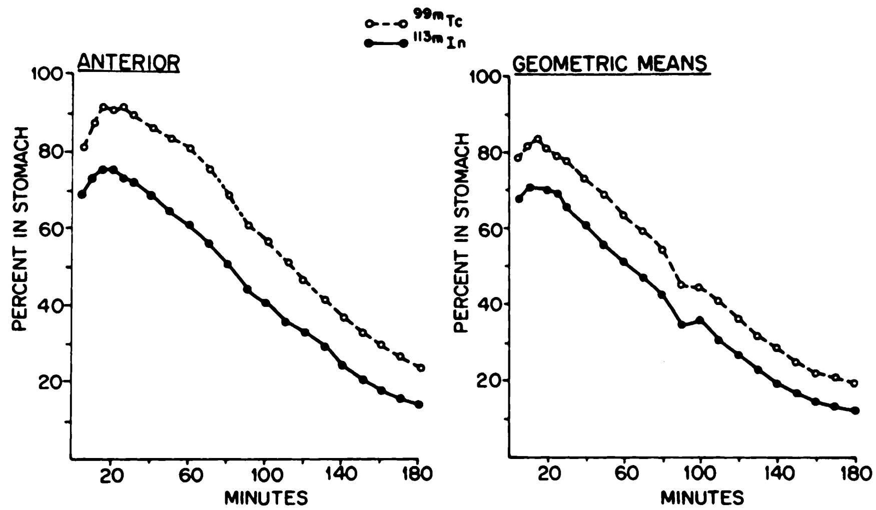

FIG. 3. Time courses of gastric emptying of Tc-99m and In-113m, computed from peak anterior counts, or geometric means of peak counts, using conventional corrections. Note that wide discrepancy between curves remains largely uncorrected if geometric means are used.

matrix count (after corrections for decay and attenuation) obtained within the first 30 postcibal minutes.

Depth was also calculated using a variation of Tothill's method. In phantom studies similar to those described above, the ratio of anterior to posterior (A:P) counts within a ROI around a source was determined as the source was moved away from the collimator. In each case, counts within the anterior or posterior ROI were corrected with the programmable calculator for variations in downscatter and septal penetration during variations in the size of the ROI. While these corrections did not take into account depth-related changes, as did the computer program, they did eliminate a substantial portion of area-related error (*3,5,6*). A plot of A:P ratios versus depth in the phantom showed an exponential regression. In the gastric emptying studies, A:P ratios obtained at each counting were read against this curve to calculate the depth of the nuclide.

Since the chicken liver was labeled uniformly with both intracellular Tc-99m and In-113m, each nuclide should give the same the time course of emptying as described by the gamma camera. However, anterior movement of the meal should affect the emptying curve of the Tc-99m more profoundly than that of the In-113m because of differences in photon energy; if corrections for such movement were inaccurate, the emptying curves should disagree significantly. Superposition of the two emptying curves would indicate that corrections for septal penetration, downscatter, and anteroposterior movement of the meal were valid.

RESULTS

When conventional corrections (for decay and for downscatter using a constant factor) were applied to anterior counts, gastric emptying of In-113m paralleled that of Tc-99m throughout the time courses, but the indium curve fell below the technetium curve by about 10–15% of meal counts (Fig. 3). This discrepancy was not corrected by computing the geometric means of simultaneously acquired anterior and posterior gastric counts (Fig. 3).

These and all subsequent emptying curves were fitted by least-squares linear regressions to a line, a commonly used transformation for gastric emptying of solid foods (*1,2*). The slopes and y intercepts were calculated (Table 1). With the conventionally corrected curves obtained in anterior views, (Fig. 3), these linear transformations confirmed the visually apparent parallelism (slopes differing insignificantly) between indium and technetium curves; the indium curves, however, had significantly lower y intercepts (Table 1). This discrepancy was not altered by utilizing the geometric means of conventionally corrected anterior and posterior gastric counts.

Separations between indium and technetium curves undergoing conventional analyses were wider with this liver meal than with a glucose meal used in a companion study (*3*). However, the average size of the gastric region of interest (ROI) with the liver meal was significantly smaller than with the glucose meal (Fig. 4). Since the effects of septal penetration and scatter increase as the gastric ROI decreases in size (*5,6*), the wider discrepancy in the present study between the indium and technetium curves undoubtedly arose from the increased amount of septal penetration and scatter that was not corrected by conventional methods.

When corrections were made for septal penetration and scatter with a calculator program, the indium and technetium curves were brought much closer together (Fig. 5). The geometric means of calculator-corrected anterior and posterior gastric activities brought the two

TABLE 1. SLOPES AND Y INTERCEPTS (MEANS ± w.e.) FROM LEAST-SQUARES LINEAR REGRESSIONS OF EMPTYING DATA

	Slope	Intercept	50% Emptied*
1. Conventional corrections			
a) Anterior In-113m:	0.41 ± .01‡	83 ± 3†	74 ± 10†
b) Anterior Tc-99m:	0.40 ± .02	95 ± 2	115 ± 11
c) Geom. means In-113m:	0.41 ± .01‡	77 ± 3†	66 ± 7†
d) Geom. means Tc-99m:	0.44 ± .02	90 ± 4	93 ± 10
2. Calculator corrections			
a) Anterior In-113m:	0.49 ± .01†	106 ± 3	114 ± 8‡
b) Anterior Tc-99m:	0.43 ± .02	103 ± 3	127 ± 12
c) Geom. means In-113m:	0.49 ± .01†	96 ± 4	95 ± 9‡
d) Geom. means Tc-99m:	0.45 ± .02	94 ± 4	100 ± 11
3. Computer corrections			
a) Anterior In-113m:	0.43 ± .01‡	97 ± 2†	110 ± 7‡
b) Anterior Tc-99m:	0.41 ± .03	95 ± 2	110 ± 8

* Min required to empty 50% of the liver meal, mean ± s.e., as calculated from slopes and intercept values for each individual. Because of the differing *y* intercepts, this parameter is the most useful one for comparing emptying of the In-113m vs. the Tc-99m.

† $p < 0.05$, In-113m vs. Tc-99m, by paired t-test.

‡ No significant difference between value for In-113m and Tc-99m.

curves still closer together (Fig. 5), as did the computer program (Fig. 6). In fact, the computer program, which corrected for depth by using P:S ratios, produced nearly the same curves as the geometric means after calculation of corrections for septal penetration and scatter (Figs. 5 & 6, Table 1) but with a slightly gentler slope and longer 50% emptying time (Table 1). Superposition of the In-113m curve on the Tc-99m curve was slightly better with the P:S method.

Whereas the conventional linear regressions of the data (Table 1) accurately reflected the actual time courses (Figs. 3-6), they did not lend themselves to easy comparisons. Theoretically, all time courses should have had *y* intercepts at or close to 100%. Significant early anterior movement of Tc-99m would produce an apparent initial slow emptying phase, with a shift of the *y* intercept above 100%, whereas significant septal penetration and scatter by photons from In-113m, conversely, would create an apparent downward shift in the *y* intercept (Table 1). Since all gastric ROI counts were normalized to 100% (of total abdominal activity), regressions intercepting the *y* axis significantly above or below 100% could not easily be judged for parallel emptying by their slopes alone. As such aberrant intercept values distorted the normalization, times of half-emptying (computed from both slope and intercept values) allowed a more realistic comparison of emptying of In-113m with that of Tc-99m. When conventional corrections were used, the 50% emptying was significantly different between the two nuclides; but when calculator or computer corrections were applied (with or without the use of geometric means with calculator corrections) the two nuclides were seen to have comparable half-emptying times (Table 1).

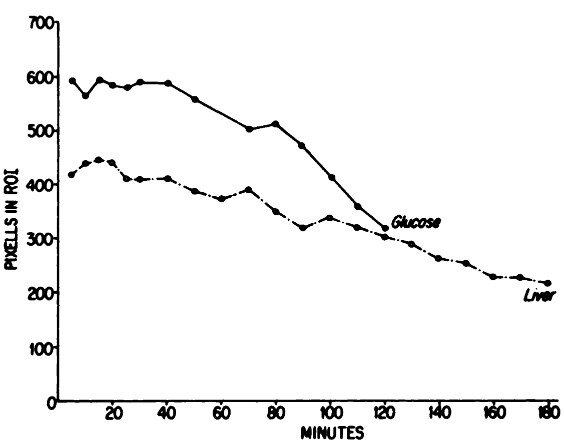

FIG. 4. Average number of pixels in the gastric ROIs with time after a 20% glucose meal (*3*) versus liver-beef stew meal.

Another method for judging parallel emptying of the two nuclides was to recompute the regressions so that all least-squares regressions had a defined *y* intercept of 100%. With such recalculations (Table 2) parallel emptying of the two nuclides was noted only when corrections were made for errors related to both area and depth, namely with the geometric means of the calculator-corrected data or with the computer corrections.

The depths of the In-113m and the Tc-99m from the collimator surface were determined by analyses of both the P:S ratios and the A:P ratios (modified Tothill method). P:S analyses indicated that the nuclides were about 2 cm more anterior compared with analyses of A:P ratios (Fig. 7). Nevertheless, both methods detected

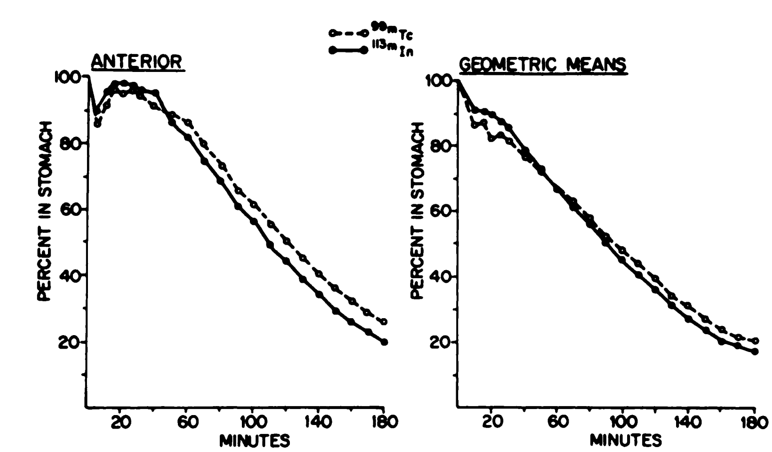

FIG. 5. Recomputation of curves in Fig. 3 with added calculator corrections for area (see text).

about 2–3 cm of anterior movement of nuclide-labeled liver meal during the 3 hr of the test. Most of this anterior movement took place within the first 30 postcibal minutes; but A:P analyses showed continued anterior movement up to 70 min, whereas analyses of P:S ratios showed essentially no further anterior movement from 30–120 min. After 120 min, P:S analyses indicated that the In-113m moved posteriorly, away from the collimator; but this posterior motion was not confirmed either by P:S analyses of the Tc-99m (at least for the period 120–160 min) or by analyses of A:P ratios for either nuclide (Fig. 7).

DISCUSSION

The present experiment confirms again the necessity of correcting ROI counts for septal penetration and scatter if quantitative data are required. Without such corrections a large underestimate of gastric content of nuclide is introduced. This error is especially large when, in the case of a solid food meal, the gastric ROI is small. With the 400-keV collimator, the error affected predominantly the In-113m curve; but we have shown in previous phantom studies (*7*) that a similarly large error may affect emptying curves when Tc-99m is counted with a 140-keV parallel-hole collimator.

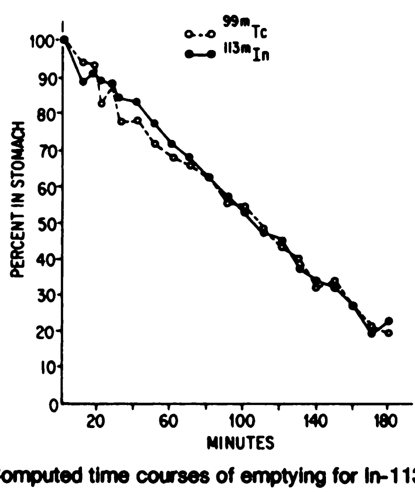

FIG. 6. Computed time courses of emptying for In-113m and Tc-99m using corrections for decay, area, and depth based on analyses of anterior peak-to-scatter ratios for each nuclide.

In this group of six subjects, our method of correcting for changes in depth, using P:S ratios, gave corrected values similar to those of Tothill's method, which utilizes geometric means (*1*,*2*).

Both methods showed marked variation in the magnitude of anterior shifts in individual subjects. When subjects were ranked according to the degree of anterior movement detected by each method, there was fair correspondence in ranking between one method and the other (with the exception of one subject). It is probable that anatomic variations within subjects and their effect on scatter accounted for any discrepancies. It is impos-

TABLE 2. SLOPES OF LINEAR REGRESSIONS FROM A Y INTERCEPT OF 100%

Data source	k, Mean ± s.e.
1. Conventional corrections	
a) Anterior In-113m:	0.55 ± .02†
b) Anterior Tc-99m:	0.43 ± .04
c) Geom. mean In-113m:	0.60 ± .04†
d) Geom. mean Tc-99m:	0.52 ± .04
2. Calculator corrections	
a) Anterior In-113m:	0.44 ± .03†
b) Anterior Tc-99m:	0.40 ± .04
c) Geom. mean In-113m:	0.52 ± .04‡
d) Geom. mean Tc-99m:	0.50 ± .04
3. Computer corrections	
a) Anterior In-113m:	0.45 ± .03‡
b) Anterior Tc-99m:	0.45 ± .03

* Fitted to the line $y = 100 - kt$, where k, the slope $= \frac{100\Sigma t - \Sigma ty}{\Sigma t^2}$.

† k for In-113m significantly different ($p < 0.05$) from k for Tc-99m; paired t-test.

‡ k for In-113m not significantly different from k for Tc-99m.

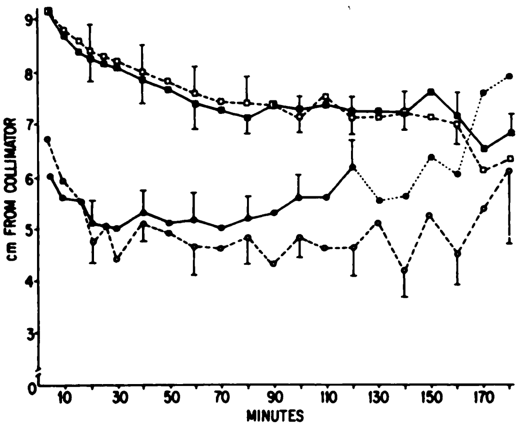

FIG. 7. Average distance of nuclides from collimator (ordinate) against time after meal (abscissa) computed for each nuclide from A:P ratios (hollow square = Tc-99m, solid square = In-113m) and P:S ratios (hollow circle = Tc-99m, solid circle = In-113m). Dotted line for P:S computed depth for In-113m during last hour of test indicated that actual counts for In-113m within gastric ROI were fewer than 5000. Such low gastric activity may have created false impression of rearword movement (see text).

sible to determine which of the two methods was more accurate in detecting real movement, since there is no way to judge such movement that does not depend on the use of scintillation detectors. Nevertheless, both methods independently confirmed a significant anterior movement of the chicken-liver marker.

When either method was used to correct the time course of emptying, both the In-113m and the Tc-99m were found to empty in parallel (Tables 1&2), a major criterion by which the validity of corrective techniques can be judged in the present study. Furthermore, pertinent comparisons (between 50% emptying times in Table 1 or between corrected slopes in Table 2) revealed only about a 10% difference between values derived from the two methods of correcting emptying times for changes in depth. Thus, whatever the discrepancies between the two methods, the outcome in computational corrections was quite similar.

Aside from the inconvenience of rotating subjects, the Tothill method has the theoretical disadvantage of not correcting for increasing septal penetration, scatter, and downscatter with increasing depths from the collimator, especially on posterior counting, where distances from stomach to collimator are larger (see Fig. 2).

The conventional Tothill corrections proved to be inadequate in both this and the companion study because they did not use any corrections for significant septal penetration and scatter. Even though these latter corrections vary with depth, the calculator program—which corrected both anterior and posterior gastric ROI counts for septal peneration and scatter at an arbitrary depth of 6 cm—improved the effectiveness of the geometric-mean corrections. That such an arbitrary correction worked, despite the known effects of depth (Fig. 2) on these corrections, probably reflected the relative magnitude of area- versus depth-related errors. For example, the area-related error for the 400-pixel ROIs for In-113m was about 20% (Fig. 2); but changes in depth of the In-113m from the collimator from 2 to 10 cm would vary this area-related error only from 17 to 22%.

Increased scatter made visual definition of the posterior gastric ROI impossible in one subject in a previous study (*3*), after the first 30 postciabl minutes. Attenuation by the spine may introduce additional errors in posterior counting. The effects of such error theoretically should be to make the nuclides appear more anterior than they really were, yet the depths computed from the A:P ratios were posterior to those computed from the P:S ratios.

Analyses of the P:S ratios are hindered by scatter of gut radiation into the gastric ROI. Ordinarily such scatter is minimal (*3*). That such an error may operate, however, is apparent from analyses of depth shown in Fig. 7. Low absolute counts from In-113m in the gastric ROI were encountered in all subjects during the last hour of the test because of (a) a purposefully low ratio of In-113m to Tc-99m activity in the initially prepared livers (to minimize errors from crosstalk),* (b) rapid nuclear decay of gastric In-113m, and (c) gastric emptying of the liver tracer. When the absolute counts of In-113m dropped to low levels, minor scatter from intestines had a proportionally larger effect on P:S ratios, creating the impression of posterior movement of the In-113m relative to the Tc-99m. This error might be reduced by analyzing P:S ratios from a small area within the gastric ROI, a modification currently under study. At any rate, scatter from the gut should make the nuclides appear farther back than they were, yet the P:S analyses placed them anterior to depths computed from the A:P analyses.

Aside from the problem with scatter from the gut, the P:S method is potentially less accurate with Tc-99m than with In-113m because of the much smaller shift in P:S ratio with Tc-99m depth (*9*) (Fig. 1). (Indeed, depths computed in this study for Tc-99m fluctuated among the six subjects more widely than those computed for In-113m, a probable outcome of this problem.) Also minor discrepancies between the two nuclides in the time courses of depth (Fig. 7) may have reflected this same problem.

Whatever its limitations, the P:S and A:P methods detected a similar magnitude of anterior movement, with both liquid (*3*) and solid meals. Furthermore, the P:S method produced a better superposition of emptying curves for In-113m and Tc-99m in the two studies than did the Tothill method. The P:S method is thus equally satisfactory for clinical and research studies.

The magnitude of area-related errors (septal penetration, downscatter) versus depth-related errors merits comment. Some idea of the relative magnitudes can be gained by inspection of the 50% emptying times in Table 1, or the slopes in Table 2. The magnitude of error can be estimated by dividing the mean half-time (Table 1) or corrected slope (Table 2) for Tc-99m by the comparable value for In-113m. If correction is adequate, this quotient should be 1.00. With anterior counting using conventional corrections, there was a 17–36% discrepancy between the two values. This was reduced to 13–29% when geometric means were used with conventional corrections. On the other hand, applying calculator corrections for area-dependent septal penetration and scatter reduced differences to 9–10% with anterior counts and to 4–5% when geometric means were used along with calculator corrections for area effects. The P:S method reduced discrepancies to zero.

These comparisons indicate that the more important source of error is related septal penetration and scatter, and that the error from changing attenuation with changes in depth is relatively smaller. Despite theoretical limitations, the demonstrated value of both the P:S method and the modified Tothill method in giving satisfactory corrections probably relates to the fact that errors from changes in depth are much smaller than area-related errors. Both methods eliminated most of the area-related errors regardless of computed depths.

The exact error cannot be determined, since there was no independent means of measuring gastric emptying. It should be noted that the P:S method not only resulted in identical half-emptying or adjusted rate constants for the two nuclides (Tables 1 & 2) but also produced values much closer to the area-corrected anterior curves than did the A:P method. If the P:S values accurately reflected what really happened, errors from correcting anterior peak counts only for area, but not for changes in depth, are of the order of 10% or less.

The need for increased accuracy, and thus for the use of corrections similar to these, depends on the application. For routine clinical testing, corrections are probably not needed to distinguish abnormal from normal gastric emptying. For clinical investigations in which it is important to measure absolute rates of emptying, corrections similar to these may be quite important. For example, area-related errors will be exaggerated by small meals or in subjects with gastric resections, where projected ROIs will be smaller than those recorded here. Alternatively, errors from anteroposterior shifts may be greater when subjects consume test meals larger than this one (*8*,*10*).

In summary, two independent methods have confirmed significant but variable anterior movement of nuclide-labeled chicken liver during the course of gastric emptying. This source of error can be corrected about as well from analysis of anteriorly acquired peak-to-scatter ratios as from Tothill's method using geometric means. Area-related errors, due to septal penetration and scatter of photons, may be even more important than errors due to anteroposterior movements of the stomach. The latter error is probably less than 10%.

FOOTNOTE

* Decay-corrected, maximum total matrix counts gave a Tc-99m: In-113m ratio of 7.75 ± 0.7 in this study.

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