Left Anterior Oblique Projection and Peak-to-Scatter Ratio for Attenuation Compensation of Gastric Emptying Studies

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Compensation for soft-tissue attenuation is necessary for accurate quantitation of nuclear gastric emptying studies. We sought an attenuation compensation method that would require the acquisition of images from a single projection, thus allowing for continuous dynamic acquisition. We investigated the use of the left anterior oblique (LAO) projection and the peak-to-scatter ratio (P/S) method. Phantom studies indicated that the P/S was not only a function of the amount of overlying attenuating material but also a function of the activity in the small intestine. Two models for the P/S method were developed, one that considered the activity in the small intestine and one that did not. A series of 27 patients (21 for solid gastric emptying and six for liquid gastric emptying) were studied comparing the results using the geometric mean (GM) method with the two P/S methods, the LAO and the uncorrected anterior (ANT) projection. The uncorrected ANT view for solid gastric emptying underestimated the percent emptying at 60 min by ~ 7%. The P/S method did not adequately compensate for attenuation. The use of the LAO projection yielded results that were highly correlated and unbiased when compared to the GM method. Accurate estimates of liquid gastric emptying can be obtained without attenuation compensation.

J Nucl Med 30:233–239, 1989

Accurate quantitation of gastric emptying studies requires compensation for soft-tissue attenuation. A number of reports have demonstrated that uncompensated studies underestimate gastric emptying and that the error may be considerable in some patients (*1–4*). This underestimation is the result of variation in the thickness of the overlying tissue as the radiolabeled meal moves from the fundus of the stomach to the more anterior antrum (i.e., towards the Anger camera face). The most common method of compensation for this varying photon attenuation is the use of the geometric mean of the counts obtained from conjugate views (GM method) (*2,3*). Although the GM method has been shown to be straightforward and effective, it requires the acquisition of both anterior (ANT) and posterior (POST) views which, in turn, necessitates either the use of a dual-headed camera or frequent repositioning of the patient during the course of the study. Since dual-headed cameras are not available in most institutions, we sought a method of attenuation compensation that would allow continuous dynamic acquisition from a single view.

We, initially, investigated the peak-to-scatter ratio (P/S) method (*5,6*). This method incorporates the fact that increasing the amount of overlying tissue should, in turn, increase the amount of scattered radiation and thus the ratio between the counts in the photopeak and a lower energy scatter window should be negatively correlated with the thickness of the overlying attenuating material. The feasibility of this method was investigated through experimentation with phantoms that stimulated the activity in the gastrointestinal system during a clinical study.

We also investigated the use of the left anterior oblique (LAO) view as an alternative new method for attenuation compensation of these studies. We chose this view since, in this projection, the activity within the stomach moves essentially parallel to the face of the Anger camera, thus minimizing the variation of attenuation during the study.

Received Apr. 4, 1988; revision accepted Oct. 11, 1988.

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The clinical utility of both these methods was investigated by comparing their resultant parameters of gastric emptying to those using the GM method on a series of patients. Both solid and liquid gastric emptying were evaluated in this study.

METHODS

To investigate the feasibility of the P/S method, a phantom study was performed. The setup for the study is shown in Figure 1. Two 250-ml saline bags, one modeling the stomach and one modeling small intestine activity, were placed in a water tank. Different numbers of Plexiglas sheets (each 1.27 cm thick) were placed between the water tank and the Anger camera to model the varying amounts of overlying tissue. Five hundred microcuries of technetium-99m (^{99m}Tc) were placed in the "stomach" bag and the activity in the "small intestine" bag was varied from 0 to 2.0 mCi of ^{99m}Tc.

The phantom was placed such that the Plexiglas sheets were flush against the camera's collimator face. A large field-of-view camera (GE 400AT) interfaced to a nuclear medicine computer (Siemens MaxDELTA System) was used. The data were acquired into two energy windows: a photopeak window (135–150 keV) and a scatter window (105–120 keV).

For the clinical studies, our standard solid meal consisted of three egg whites labeled with 500 μCi of [^{99m}Tc]sulfur colloid cooked with one-half teaspoon of butter, served as an egg sandwich between two pieces of toast and followed by 100 cc of water. Five hundred microcuries of [^{99m}Tc]sulfur colloid mixed with 500 cc of water was administered for the liquid gastric emptying studies. If liquid and solid studies were performed on the same patient, they were performed on different days.

The patients were imaged in the morning after having fasted overnight. One-minute images were acquired on a large field-of-view Anger camera (either the GE 400AT or the Siemens ZLC 3700) with a low-energy, general purpose collimator, connected to the computer described above, in the ANT, POST, and LAO views immediately after ingestion of the meal and every 15 min, thereafter, for a minimum of 90 min. The ANT images were acquired into the same two energy windows as the phantom study (105–120 keV and 135–150 keV). Patients were imaged standing but were generally sitting between images. Regions of interest (ROIs) were drawn on the computer. For each image, a stomach region, a large scatter region, and a small intestine region were drawn on the ANT view along with a stomach region on the POST and LAO views. From these regions, ANT, POST, LAO, small intestine (SI), peak (P), and scatter (S) counts were obtained at each time point. From these data, the GM and the P/S were calculated.

To investigate the P/S method, the above data were acquired on seven consecutive patients studied for solid gastric emptying. Multiple regression analysis was used to obtain a fit between the P/S, the SI activity, and the attenuation compensation factor obtained using the GM method at each time point. Two P/S models were evaluated: one that utilized the SI activity (the P/S + SI model) and one that did not (the P/S model). Compensation factors for the P/S model were based on the results of the phantom study, whereas those for the P/S + SI model were obtained from the above multiple regression results with patient data. The two models were:

$ACF = 0.826\ P/S - 0.91$ for the P/S model and

$ACF = 0.0872\ P/S + 746\ (1/SI) + 0.715$ for the P/S + SI model,

where ACF is the attenuation compensation factor and SI is the small intestine activity.

At this point, a second group of ten patients were studied for solid gastric emptying. Decay-corrected time-activity curves were obtained for the ANT method, GM method, P/S method, and the P/S + SI method. Once beyond the lag phase, a linear fit was applied to each time-activity curve, and from the fit, the parameter percent gastric emptying at 60 m (% GE) was determined. The data from these patients were used to compare the % GE results from the two P/S methods with results of the GM method. The results from uncorrected data from the ANT view were also compared with those from the GM method.

In 21 patients, data were acquired from the LAO, ANT, and the POST projections. Since we were interested in imaging patients while they were sitting, we also compared the results of the sitting LAO to the standing LAO and the ANT projection as to their correlation with the GM values in ten of these patients. The % GE parameter was again calculated from the time activity curves, and the values for the LAO data were

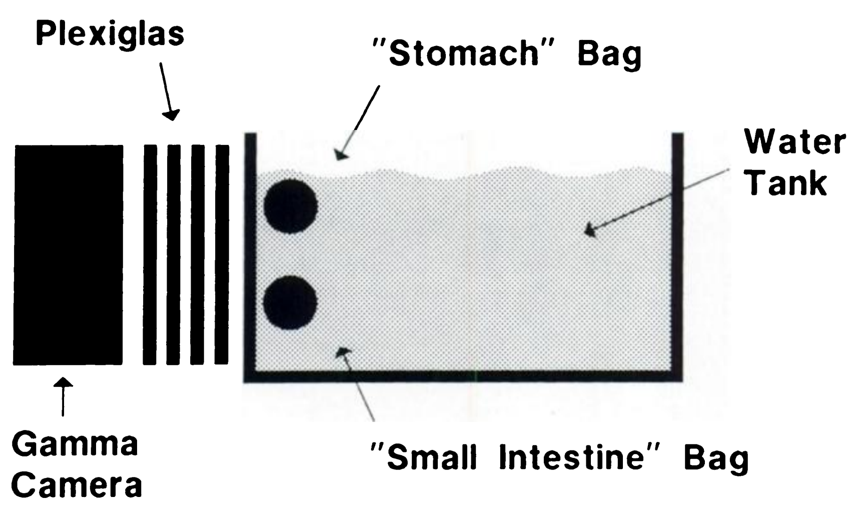


FIGURE 1
P/S phantom setup. Two saline bags simulating the stomach and the small intestine were placed within a water tank. Plexiglas sheets were placed between the water tank and the gamma camera to simulate varying amounts of attenuating material.

compared to both those from the GM method and the uncorrected data from the ANT view.

The necessity of attenuation compensation in liquid gastric emptying was evaluated in a series of six patients. One-minute images (ANT, POST, and LAO projections) were collected every 10 min for 60 min. The same set of ROIs were drawn as for the solid gastric emptying study and decay-corrected time-activity curves were obtained. Since liquid gastric emptying is best modeled by an exponential curve, the half-life ($T_{½}$) was used to characterize the emptying curve. Estimates of $T_{½}$ for the six patients were compared for the four attenuation compensation methods described above.

TABLE 1
Solid Gastric Emptying: Comparison of % Emptying at 60 min (%) to the Geometric Mean Method

Method	Correlation coefficient (r)	Standard error of the estimate	Mean difference from GM (standard error)
ANT	0.957	5.93	7.08 (1.84)
P/S	0.948	4.23	7.00 (2.01)
PS + SI	0.889	6.03	0.29 (2.54)
LAO	0.956	5.31	−0.01 (1.58)

RESULTS

The results from the phantom study are plotted in Figure 2. The P/S is negatively correlated with the amount of attenuating material, and the relationship was highly linear once beyond 3.8 cm (1.5 in). However, the added scatter from the small intestine tended to shift the curve downward as seen on Figure 2. This suggested that a model which not only incorporates the P/S but also the SI activity may be more appropriate than one that just considers the P/S. Two P/S models were developed based on the results of the phantom studies and the multiple regression of the P/S, the SI activity, and the attenuation compensation factor from the GM method. The equations for these models were described in the methods section of this paper. The correlation of the % GE values from these models were compared to those using the geometric mean method with the next ten patients. The results are summarized in Table 1. Also in this table are the results obtained from the ANT and LAO projection, uncorrected for attenuation, for the same ten patients.

All methods resulted in % GE values that correlated well with the GM values (r in excess of 0.89 in all cases). The uncorrected ANT and the P/S model had mean differences from the GM method of 7%, underestimating the % GE by that amount. On the other hand, the P/S + SI model and the uncorrected LAO projection data yielded values which were statistically identical to the GM values (paired t-test, $p > 0.9$).

Encouraged by the LAO results, we extended that part of the study to an additional 11 patients (total 21 patients). These results are summarized in Table 2 and graphed in Figure 3. The results are shown with the results of uncorrected data from the ANT projection. The correlation in both cases was again high ($r > 0.94$) with s.e.e. values in the 4–5% range. As in the above study, the ANT values underestimated the % GE by 7% while the LAO values were not significantly different than the GM values. Data from the 10 patients that were imaged in the LAO projection, both sitting and standing are also listed in Table 2 and plotted in Figure 4. For this small number of patients, the sitting LAO data is superior to the others.

The results of the liquid gastric emptying study are shown in Table 3. The differences are measured in minutes since this is the unit for $T_{½}$. The P/S + SI method was seen to be the best when compared to the GM method ($r = 0.946$, s.e.e. = 3.4 min). However, the uncompensated ANT data yielded very similar results ($r = 0.940$, s.e.e. = 3.5).

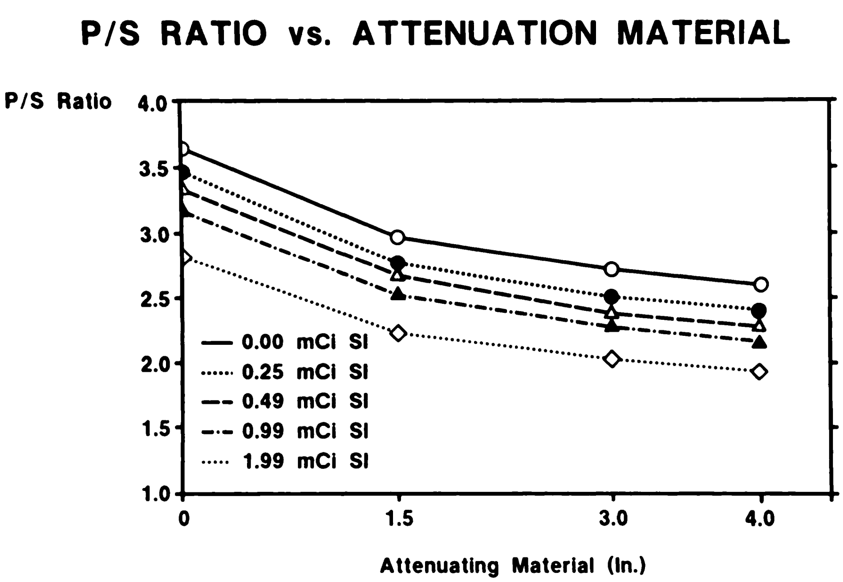


FIGURE 2
P/S vs. attenuating material. The phantom study results are shown with P/S plotted as a function of the thickness of the attenuating material (in inches) for varying amounts of "small intestine" (SI) activity. Although the P/S is negatively correlated with the amount of attenuating material, increasing the amount of SI activity leads to a downward shift of the plots.

TABLE 2
Solid Gastric Emptying: Comparison of % Emptying at 60 min (%) to the Geometric Mean Method

View	Correlation coefficient (r)	Standard error of the estimate	Number of patients	Mean difference from GM (standard error)
ANT	0.941	5.18	21	7.07 (1.12)
LAO	0.953	4.39	21	0.83 (0.94)
LAO sit	0.967	2.62	10	1.13 (0.78)
LAO	0.922	4.38	10	1.20 (1.31)
ANT	0.884	5.13	10	7.16 (1.54)

DISCUSSION

The need for attenuation compensation of clinical gastric emptying studies is somewhat controversial; however, it is generally agreed that for accurate quantitative physiological studies, attenuation compensation should be performed (*1–4*). The GM method has been shown to be an effective technique for correcting attenuation, but it requires acquisition of conjugate views. Simultaneous, continuous acquisition would require a dual-headed camera, which is not generally available in most nuclear medicine laboratories. Even with a dual-headed camera, upright imaging, which is more physiological, would pose technical problems. The alternative is to rotate the camera or patient from the anterior to the posterior projections and, therefore, image the patient intermittently. Typically this is performed every 15–20 min for 90 min to 3 hr. This procedure is technically more demanding, and accurate timing is critical. Intermittent imaging limits the number of data points available for regression analysis compared to continuous acquisition and could affect the reliability of the results. The lag phase of the solid gastric emptying time-activity curve is difficult to characterize when intermittent imaging is performed. There are other limitations to the GM method. Relatively lower counts

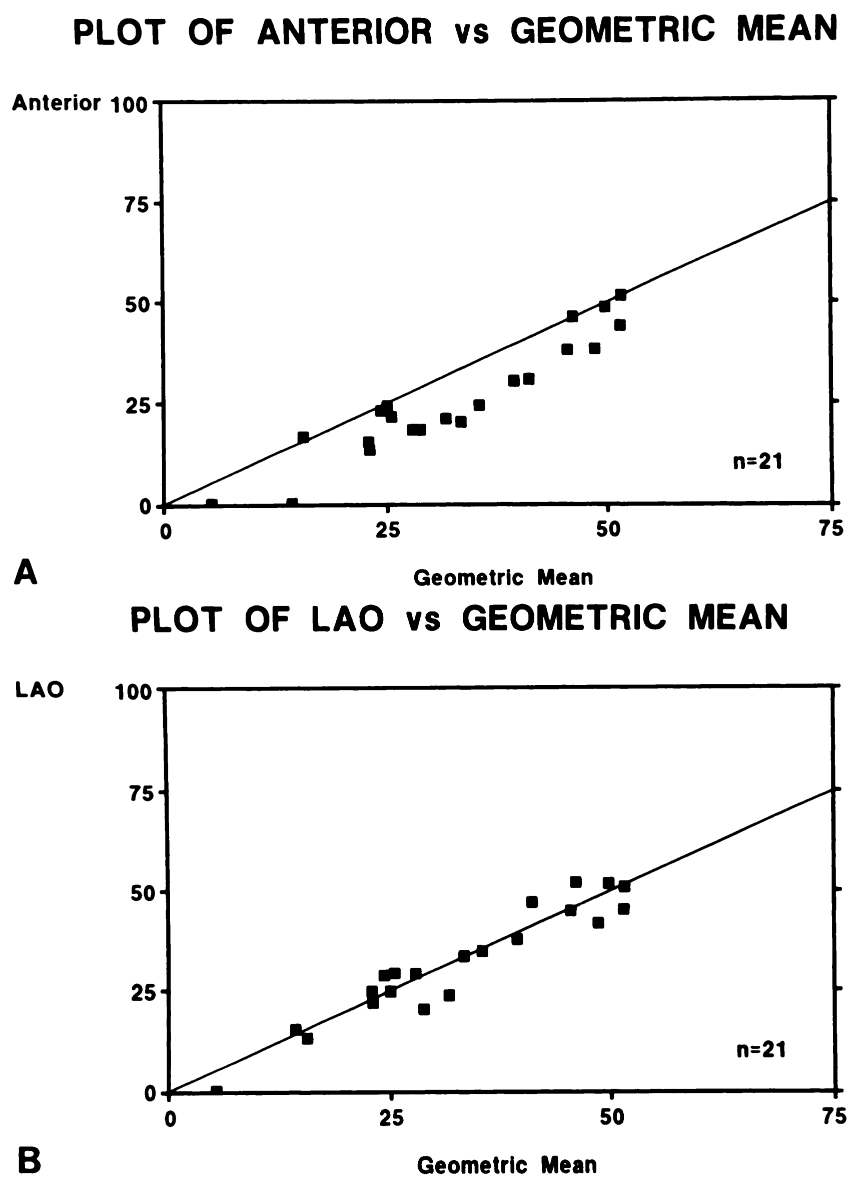
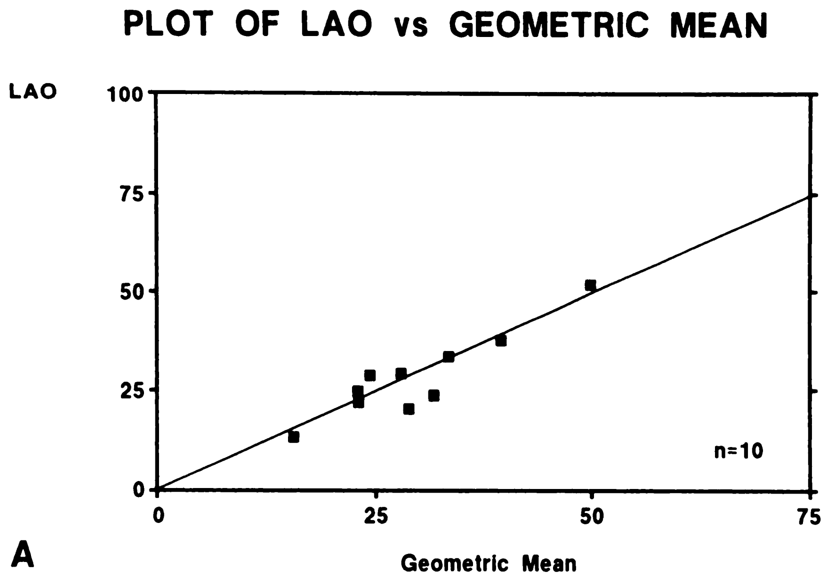
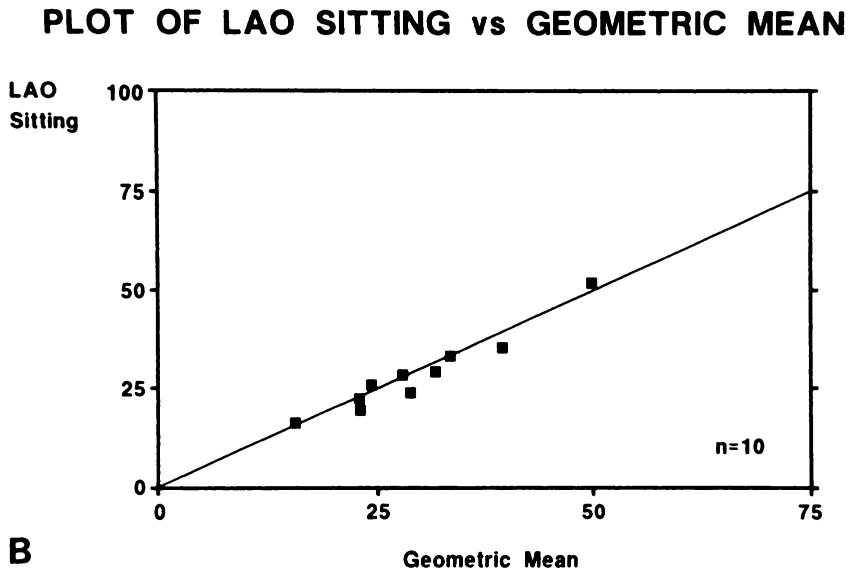


FIGURE 3
LAO and ANT results vs. GM method. The % GE values (21 patients) for the uncorrected ANT (A) and LAO (B) are plotted versus the results obtained with the GM method. The solid line in each case represents the line of identity for the GM results. The ANT values underestimate the % GE whereas the LAO values are unbiased compared with the GM method.



A



B

FIGURE 4
LAO and LAO sitting vs. GM method. The % GE values (ten patients) for the LAO (A) and the LAO with the patient sitting (B) plotted against the results obtained with the GM method. The solid line in each case represents the line of identity for the GM results. Both LAO acquisitions yield highly correlated and unbiased results with respect to the GM method.

in the POST view can lead to greater noise in the GM value at each data point, and sometimes it makes it difficult to accurately define the POST ROI. There can also sometimes be attenuation of antral counts from the spine on the POST image.

In seeking an attenuation compensation method that required the acquisition of images from a single view, two methods had been described in the literature. The P/S method has been investigated for both liquid and solid gastric emptying (*5,6*). These studies compared the results for radionuclides of two different energies (^{99m}Tc and ^{113m}In) through both phantom and clinical studies. They concluded that attenuation compensation yielded no significant improvement in liquid studies, but for solid studies, the P/S method yielded similar results to the GM method. They stated that this correction was small when compared to errors introduced by septal penetration and scatter. Collins et al. investigated the use of an image from the lateral vertical position of the activity within the stomach (*7,8*).

The P/S method was the method which seemed to best meet our needs. The LAO view was a possible alternative solution. Attenuation would be minimized since most of the activity would move parallel to the face of the camera, thus minimizing the variation in attenuation.

TABLE 3
Liquid Gastric Emptying: Comparison of $T_{½}$ Values (min) to the Geometric Mean Method

Method	Correlation coefficient (r)	Standard error of the estimate	Mean difference from GM (standard error)
ANT	0.940	3.5	2.5 (1.7)
P/S	0.881	6.9	−5.2 (2.5)
PS + SI	0.946	3.4	1.8 (1.6)
LAO	0.862	5.6	2.1 (2.3)

The phantom study results in Figure 2 demonstrated the potential of the P/S method. A negative correlation was seen between P/S and the amount of attenuating material which should allow for a correction to be generated. However, our study demonstrated that scatter from neighboring activity (in the SI, for instance) affects the P/S value. This is most likely because the scatter image is very low resolution, leading to overlap of the two regions. Thus, the P/S may vary due to an increase in the SI activity rather than a change in the thickness of the overlying tissue. We, therefore, sought two P/S models: one that incorporated SI activity into it, and one that did not. In the clinical evaluation, the P/S method was seen to be unsatisfactory. The P/S model did not substantially improve the determination of the percent of gastric emptying from the uncorrected ANT data. This is probably because the complex spatial distribution of the activity within the patient does not lend itself to the simplifying assumptions used in the P/S model and demonstrated in the phantom study. The inclusion of the SI activity into the model did improve the performance of the technique; however, it was unclear if this improvement was due to the effect demonstrated in the phantom study. The coefficient from the multiple regression for the SI activity was in the opposite direction than indicated by the phantom study. The reason the inclusion improves the GE model may be due more to the fact that the SI activity itself indicates gastric emptying and not so much a function of the P/S ratio. For these reasons, we do not feel that the P/S method appropriately corrects for attenuation, and we do not recommend its use.

The use of the LAO projection, on the other hand, has proven to be an exceedingly simple and effective method of compensating for attenuation. The time-activity curves from the LAO view yield slopes that are not significantly different than those of the GM curves, yielding essentially the same % GE values (mean absolute difference of < 4%). In addition, it was seen that it did not matter whether the LAO view was acquired with the patient standing or sitting which will allow the patient to sit during the entirety of the lengthy study (60–120 min). We now routinely use the time-activity curve from the LAO view to characterize the rate of solid gastric emptying.

One issue that has received attention in nuclear gastric emptying literature is the clinical significance of the so-called "lag" phase (*4,9*). The best parameter for characterizing lag phase remains to be seen. It is clear that images must be acquired rapidly (at least once every minute) for the first 15 min of the study. Unfortunately, a dual-headed camera is necessary to determine whether the LAO is appropriate to characterize the lag phase since it is, otherwise, impractical to acquire ANT, POST, and LAO views each minute for 15 min.

For liquid gastric emptying, although the P/S + SI model correlated the best with the GM method, the uncompensated ANT view performed nearly as well. Based on these results, it was decided that accurate estimates of $T_{1/2}$ from liquid gastric emptying studies could be obtained without attenuation compensation. This is due to the fact that the activity very quickly moves to the antrum of the stomach, and thus the motion of the activity within the stomach does not lead to the same problems as it does for solid emptying.

In summary, the ANT view, uncorrected for attenuation, yielded % GE values for solid emptying that underestimated by ~ 7% those obtained using the GM method and our clinical protocol. The P/S method did not adequately compensate for attenuation in solid gastric emptying studies and is not recommended. The use of the data from the LAO projection, that was not otherwise corrected for attenuation, yielded values of % GE that were not only highly correlated with the GM results but were also unbiased. In addition, performing the study in the LAO projection with the patient sitting rather than standing was equally accurate. We, therefore, recommend the use of the LAO view when performing a solid gastric emptying study from a single projection. Accurate estimates of liquid gastric emptying can be obtained without attenuation compensation.

ACKNOWLEDGMENT

The authors thank Saroj Patel for her technologic assistance with these studies and Sandra K. Pruitt for her careful preparation of the manuscript.

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