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Stomach frame-count-based attenuation correction of dynamic posterior view gastric emptying scintigraphy with continuous acquisition in children

Xinhua Cao¹, Xiaoyin Xu², Laura Drubach¹, and Frederic H. Fahey¹

¹Department of Radiology, Division of Nuclear Medicine and Molecular Imaging, Boston Children's Hospital and Harvard Medical School, 300 Longwood Ave., Boston, MA 02115, USA

²Department of Radiology, Brigham and Women's Hospital and Harvard Medical School, Boston, MA, USA

Abstract

Background—When performing dynamic gastric emptying scintigraphy with continuous acquisition in children, a single posterior view acquisition is preferred because it allows the young patient to more easily interact with a parent or technologist even though this method tends toward overestimating gastric emptying.

Objectives—The objective of our study was to develop a new attenuation correction (AC) method to improve the accuracy of the time activity curve and the measurement of residual gastric emptying from 1-h posterior images of gastric emptying scintigraphy with continuous acquisition.

Materials and methods—We developed a frame-count-based AC for gastric emptying scintigraphy from the posterior view (posterior AC method). We retrospectively reviewed 122 gastric emptying studies performed in children using conjugated posterior and anterior views, and evaluated the statistical differences between posterior only (without AC) and posterior AC using the geometric mean method as a reference standard.

Results—The residual values obtained using posterior AC were not significantly different ($P=0.813$) compared to those using the geometric mean while the values using the posterior only were significantly different ($P<0.001$) from the geometric mean.

Conclusion—The proposed method can replace the geometric mean method to estimate gastric emptying residual fraction using patient-friendly posterior view without a significant difference in 1-h gastric emptying scintigraphy with continuous acquisition.

Keywords

Attenuation correction; Children; Gastric emptying scintigraphy; Geometric mean; Posterior view

Correspondence to: Xinhua Cao.

Compliance with ethical standards

Conflicts of interest None

Introduction

Gastric emptying scintigraphy at hourly intervals up to 4 h has been commonly regarded as the standard for the quantitative measurement of gastric motility in clinic practice [1, 2]. In pediatric practice, dynamic gastric emptying scintigraphy with 1-h continuous acquisition is often required because evaluating gastric emptying in children is usually performed in conjunction with that for gastroesophageal reflux [3–8]. Gastric emptying scintigraphy with static images at hourly intervals or multiple time points is only used to evaluate gastric emptying and is without the capability to monitor gastroesophageal reflux and lag periods. By providing continuous time activity curves of the stomach and esophagus, gastric emptying scintigraphy with continuous acquisition can be used for all of these evaluations. Compensation for soft-tissue attenuation is necessary since the thickness of soft tissue varies as the labeled meal moves from the posterior gastric fundus to the more anteriorly positioned gastric body and antrum. Many reports have demonstrated that studies performed with only anterior imaging underestimate [9–12] gastric emptying, while studies performed with only posterior imaging overestimate [12–14] gastric emptying. The method generally used to compensate for tissue attenuation in gastric emptying employs the geometric mean of the counts obtained from conjugated (anterior and posterior) views. Use of single left anterior oblique has been described as an alternative method [15]. Both the geometric mean and left anterior oblique methods require positioning a detector over a patient's chest and abdomen, which is not a problem for gastric emptying scintigraphy with 20- to 60-s static imaging. However, for dynamic gastric emptying scintigraphy with 1-h continuous acquisition, having a large detector positioned anteriorly in close proximity to the patient for an hour might cause some anxiety, particularly in children, and may also limit the technologist's access to the patient [14] during that imaging. When performing dynamic gastric emptying scintigraphy in children, a single posterior view continuous acquisition is preferred because it allows the young patient to more easily interact with a parent or technologist, minimizing patient anxiety and allowing for the observation of the child at all times.

The total counts in each frame acquired during continuous gastric emptying scintigraphy acquisition would be the same after decay correction if there was not a thickness variation of overlaying soft tissue as food moves through the stomach and into the small intestine. Thus, as long as the camera covers the entire tracer distribution in the patient, any fluctuation of total frame counts (that is, stomach plus esophageal or intestinal activity) with time indicates the amount of attenuation change that occurs as the tracer moves during gastric emptying. Figure 1 shows an example of time activity curves of total frame counts with meal motion inside the stomach in a 1-h dynamic gastric emptying scintigraphy in anterior view, posterior view and the geometric mean. The total frame activity of the anterior view is great and goes up gradually with time as the radiolabeled meal moves from the gastric fundus to the gastric body and antrum, while that of the posterior view is small and goes in the opposite direction. The geometric mean of anterior and posterior frame activities lies at the middle between them and shows little change.

The objective of our study was to demonstrate a new method for stomach attenuation correction (AC) based on total frame counts to improve the accuracy of the time activity

curve and the measurement of residual gastric emptying in children using a single posterior view.

Materials and methods

Subjects and data analysis

This retrospective study included 122 consecutive children and young adults (42 male, 80 female) from 2 to 20 years old (average: 13.9 years). For this type of retrospective study, the requirement for informed consent was waived by the hospital's institutional review board. All patients underwent a 1-h dynamic gastric emptying scintigraphy using dual-detector acquisition with either an ultra-high or a high-resolution collimator. A solid meal (1 scrambled egg or 1 tablespoon of melted cheese on a small piece of toast) or liquid meal (formula or milk) labeled with ^{99m}Tc sulfur colloid (0.555 MBq/kg [15 $\mu\text{Ci/kg}$], minimum 7.4 MBq [200 μCi] and maximum 18.5 MBq [500 μCi]) was administered to the patient following a 6-h fast. Images were recorded continuously at a rate of 30 s/frame and motion correction was applied to align the stomach in 60-min consecutive frames using an automated method based on target tracking [16]. Regions of interest (ROIs) were drawn manually on the stomach in the first and last frames and their counts were determined using the posterior view, anterior view and geometric mean methods. Rectangular ROIs of abdomen and esophagus were also manually drawn (Fig. 2). The ROI of the abdomen (stomach + bowel) was used for determining the total administered activity in the meal for early emptying [17] and the esophagus region was used to monitor for esophageal reflux. Time activity curves of the stomach between the first frame and final frame were calculated using an interpolated region from the first-frame and the final-frame ROIs. Stomach counts were calculated in both the posterior and anterior views and corrected for radioactivity decay. The geometric mean was the square root of the product of the posterior and anterior counts. The gastric residual fraction (%) at 1-h postingestion was defined as the percentage of the stomach counts present in the final frame divided by the counts in the first frame. Gastric residuals were calculated using posterior only (no correction), the posterior AC described below, and geometric mean methods.

Posterior attenuation correction (posterior AC)

The proposed method for posterior view gastric emptying scintigraphy with continuous acquisition (posterior AC) was based on the assumption that the change of total frame counts with time was caused by the thickness change of overlaying attenuating tissue as the radiolabeled meal moved inside the stomach and small intestine with time. The AC was performed by compensating the attenuated counts using the fluctuation variation of total frame counts.

Stomach counts in the posterior view were further corrected using following equation

$$C_{\text{stomach}}^{\text{AC}}(t) = C_{\text{stomach}}(t) + \alpha(t)C_{\text{attenuation}}(t), \quad (1)$$

where $C_{stomach}(t)$ and $C_{stomach}^{AC}(t)$ are stomach posterior only and posterior AC counts, respectively. $C_{attenuation}(t)$ is the fluctuating counts caused by traced meal motion inside stomach and small intestines due to the thickness variation of overlaying soft tissue. $C_{attenuation}(t)$ was defined as the difference of total frame counts between the frame at t and the first frame at t_0 .

$$C_{attenuation}(t) = C_{frame}(t_0) - C_{frame}(t) \quad (2)$$

$C_{frame}(t_0)$ is the total counts of the first frame without attenuation variation and $C_{frame}(t)$ is the frame counts fluctuated with attenuation variation (Fig. 3). Considering $C_{attenuation}(t)$ is the total attenuation counts caused by the meal motion inside both stomach and small intestines, we designed a weight $\alpha(t)$ in Eq. (1) to indicate the stomach contribution to total attenuation counts:

$$\alpha(t) = \frac{C_{stomach}(t)}{C_{abdomen}(t)} \quad (3)$$

where $C_{abdomen}(t)$ is the total counts inside abdomen region.

As an example, dual head dynamic gastric emptying scintigraphy of a 14-year-old girl administered with a solid meal (Fig. 4) shows the time activity curves of gastric emptying and their gastric residual fractions (%) at 60 min using the anterior view, posterior view, proposed posterior AC and geometric mean methods.

Statistical analysis

The systematic differences and correlations of gastric residual fractions (%) using posterior only as well as the posterior AC and geometric mean methods were evaluated by performing paired t -test and linear regression analyses. A Bland-Altman analysis was performed to show agreement between the posterior only, posterior AC and geometric mean methods in the measurement of gastric residual. The differences, or measured errors of gastric residual, were further analyzed to calculate their correlations with patient age using linear regression analysis. Statistical analysis was performed using the SPSS 8.0 software (SPSS Inc., Chicago, IL, USA). Two-tailed P -values of less than 0.05 were considered statistically significant for both Student's t -test and regression analysis.

Results

Gastric residual fractions (%) were compared in Table 1 using the paired t -test. The measured errors of posterior only and posterior AC compared to the geometric mean method as a standard were -6.17 ± 6.47 and -0.09 ± 3.99 , respectively. The values attained using posterior AC were not significantly different ($P=0.813$) compared to those using geometric mean, while the values using the posterior only method were significantly different ($P<0.001$) from the geometric mean method. The linear regression and Bland-Altman graphs are shown in Fig. 5. The correlation between posterior AC and geometric mean, with a

diagonal fitting line and narrow 95% confidence interval (CI), was stronger ($r=0.986$) than that between the posterior only and geometric mean ($r=0.962$). Bland-Altman analysis in the comparison of posterior only, posterior AC and geometric mean demonstrated that the mean difference line of posterior AC is located very close to the zero line (-0.09) with a narrow 95% CI, while that of posterior only is at -6.17 below the zero line with a wide 95% CI (Fig. 5). This means that there is a more perfect agreement of the posterior AC and geometric mean methods than that of the posterior only and geometric mean methods in respect to gastric emptying calculation.

The Pearson's correlation coefficients and linear regression equations between measured errors and patient age are summarized in Table 2 and Figure. 6. The scatter plots in Figure. 6 demonstrated that the negative measure errors between posterior only and geometric mean increased significantly with patient age ($P<0.001$), overestimating gastric emptying more and more with increasing patient age. Figure 6 shows that the measure error between posterior AC and geometric mean was not significantly associated with patient age ($P=0.195$).

Discussion

Since the first use of radionuclides to measure gastric emptying was published in 1966 [18], gastric emptying scintigraphy has been considered the standard approach to evaluating patients with symptoms that suggest abnormal gastric motility because it provides a physiological, noninvasive and quantitative measurement of gastric emptying [19]. In children, dynamic gastric emptying scintigraphy with 1-h continuous acquisition is often required to combine with a gastroesophageal reflux examination. In addition, infants and younger children without the capability of swallowing solid meals also require dynamic gastric emptying scintigraphy using liquid meals via mouth, nasogastric tube or gastrostomy tube. Since it allows both visualization and quantification of a radiolabeled meal from each compartment, dynamic gastric scintigraphy can be used simultaneously to evaluate gastric emptying time [11], gastroesophageal motility [20] and gastric antral motility [21, 22] and to quantify gastric emptying. Static gastric emptying scintigraphy with multiple time points is inadequate to evaluate the lag phase [11, 12] and the compartmentalization of food inside the stomach [21, 23] because of a low sampling rate as compared with continuous acquisition. Many experts believe that evaluating the lag phase is important [11]. Thus, by providing continuous time activity curves, dynamic gastric emptying scintigraphy with 1-h continuous acquisition in our clinical practice enabled the monitoring of gastric emptying, gastroesophageal reflux, lag periods and early emptying (Fig. 7).

Some studies have shown a poor correlation between the simple rate of gastric emptying and the patient's symptoms, suggesting that assessment of other physiological parameters may be important [24]. The determination of gastric accommodation to the introduction of a meal may be one such parameter, and this assessment requires a continuous dynamic acquisition. A correlation has been found between the degree of gastric distention and symptoms of postprandial pain and belching [25]. Early satiety, a common indication for gastric emptying scintigraphy, has been associated with early distal redistribution of the liquid phase and the

symptom of fullness has been associated with late proximal retention [26]. All of these assessments require dynamic gastric emptying scintigraphy with continuous acquisition.

Tothill et al. [27], in 1978, found that the variation in depth of radionuclide within the stomach may result in a significant error in the measurement of gastric emptying if no attempt is made to correct for gamma ray attenuation by the patient's tissues. In pediatric gastric emptying scintigraphy, we have previously demonstrated that the effects of tissue attenuation on quantitative values of gastric emptying depend on patient age, body weight and meal type [14]. For children older than 8 years and weight >30 kg, the measured error of solid meal gastric residual without AC was significant. Many correction techniques have been reported previously, including depth-corrected method using the lateral view [28], peak-to-scatter ratio method [15, 29, 30], left anterior oblique view method, and geometric mean method using conjugated posterior and anterior views. Among them the geometric mean method has been shown to be the most effective and accurate for correcting overlying soft-tissue attenuation in gastric emptying scintigraphy, but it requires placing the patient into a narrow and uncomfortable space between two detectors in order to acquire conjugated views. Both the geometric mean method with two conjugated views and the single left anterior oblique view method might cause some anxiety and incompliance when the large detector(s) are placed close to a patient for continuous 1-h acquisition. Dynamic gastric emptying scintigraphy with a single posterior detector, by contrast, provides an open space above the patient to allow for better comfort and patient access that is especially important when imaging children. However, it requires correcting for soft-tissue attenuation to avoid the overestimation of gastric emptying. The single view peak-to-scatter ratio attenuation corrections with and without small intestine activity were rejected because their mean differences from geometric mean method underestimated the percent emptying 7% and therefore does not adequately compensate for attenuation [11]. The depth-corrected method with a single view, either posterior [12] or anterior [28], required additional radiopharmaceuticals (^{99m}Tc 3.7–10 MBq [100–270 uCi]) mixed with 150 ml of water to acquire the lateral view just after continuous acquisition. In this paper, we demonstrated a new method that corrected time activity curves and gastric residuals by using the fluctuation of total frame counts with time to compensate for the attenuation variation of posterior view gastric emptying scintigraphy with continuous acquisition. The proposed method incorporates the fact that the fluctuation of total frame counts with time indicates the amount of attenuation change during the study as long as the camera covers the entire tracer distribution within the patient. This study focused on 1-h dynamic gastric emptying scintigraphy with continuous acquisition shows that the proposed method improves the standard deviation of gastric residual measures from -6.17 ± 6.47 to -0.09 ± 3.99 .

The proposed method assumes that the fluctuation of frame counts was only caused by the attenuation variation with the meal motion inside the stomach and small intestine. Therefore, it is very important to position the single posterior detector to include all activity in the chest and abdomen during the 1-h continuous acquisition in order to avoid losing counts that are outside the field of view. Lost counts will result in the underestimation of gastric emptying due to excessive compensation. Although the proposed method performs attenuation correction on the single posterior view, it can be applicable for any single-view gastric emptying scintigraphy. This frame-count-based method for dynamic gastric emptying

scintigraphy with continuous acquisition could also be used for 2- to 4-h static images obtained using single-view gastric emptying scintigraphy, but it would be critical to ensure proper camera positioning to avoid loss of counts that are outside of the field of view. The use of a fiducial marker might be helpful to assure proper positioning and align stomachs in the 2- to 4-h studies. In addition, possible tracer loss between static image acquisitions due to emesis or bowel emptying must be considered. Even if the proposed attenuation method for dynamic gastric emptying scintigraphy with continuous acquisition can be used for hourly gastric emptying scintigraphy with static acquisition, it might not be necessary to acquire the posterior view static gastric emptying scintigraphy since the short-time imaging (30 s in our clinical practice for 4-h hourly static gastric emptying scintigraphy), even having a big detector over the patient, will cause little anxiety and inconvenience. Although the standard deviation (Table 1) decreases from 6.47 in the posterior view only method to 3.99, the accuracy of the proposed method should be improved further in the future. The major source of error probably is in the winding of small intestine that goes back and forth in the posterior and anterior, thus randomly enhancing or reducing the total attenuation when the traced meal moves from stomach into small intestine. The mean error of 0.09 between the posterior AC and geometric methods indicates the randomness of measure errors. In addition, the relationship between measure error and body weight may be worth investigation.

Conclusion

The proposed frame-count-based AC of posterior view gastric emptying scintigraphy with continuous acquisition can replace the geometric mean method of conjugated views to estimate the gastric emptying residual fraction without significant difference. The patient-friendly posterior acquisition can minimize young patient anxiety and allow the physician/technologist to more easily access and observe the child at all times during the 1-h continuous acquisition.

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Fig. 1.

Gastric emptying scintigraphy in a 14-year-old girl. **a** Total frame counts in continuous 1-h study with solid food in anterior view, posterior view and their geometric mean. Attenuation increases (*posterior*) and decreases (*anterior*) apparently due to food motion at around 20 min on single view and on anterior view (**b**) and posterior view (**c**) at 1 h

Fig. 2. Regions of interest for 1-h gastric emptying scintigraphy quantitative analysis (same patient), two stomach regions at first frame and final frame, abdomen region covering stomach and small intestine and esophagus region for monitoring esophageal reflux *GES* gastric emptying scintigraphy

Fig. 3.
Attenuation counts (same patient) are defined as the fluctuation of total frame counts caused by traced meal motion inside the stomach and small intestine

Fig. 4. Stomach time activity curves and residuals of gastric emptying in a 14-year-old girl administered with a solid meal, using anterior view, posterior view, posterior AC and geometric mean methods

Fig. 5. Scatter plots for relationships (a and c) and Bland-Altman plots for mean differences (b and d) with 95% confidence intervals (CI) between gastric residual fractions (%) measured by posterior only (upper row), posterior AC (lower row) and geometric mean methods AC attenuation correction, GM geometric mean

Fig. 6.

The linear regression analysis of measure errors as the function of patient age compared to the geometric mean method. The measure error of posterior only (**a**) increases significantly with patient age ($P < 0.001$) while that of posterior AC (**b**) is not significantly associated with patient age ($P = 0.195$) AC attenuation correction, GM geometric mean

Fig. 7.

Posterior view gastric emptying scintigraphy with 1-h continuous acquisition in a 16-month-old boy with vomiting. Gastroesophageal reflux (at 40 min) and early emptying (6%) before imaging were detected

Comparison of gastric residual fraction (%) at 60 min to geometric mean method by paired *t*-test (*n*=122)

Table 1

	Residual mean ± SD	Paired difference (Mean ± SD)	Paired <i>t</i> -test	Significant 2-tailed <i>P</i>	Correlation <i>r</i>
GM	55.99 ± 23.78				
Posterior only	49.82 ± 22.63	−6.17 ± 6.47	−10.54	<0.001	0.962
Posterior AC	55.91 ± 23.49	−0.09 ± 3.99	−0.236	0.813	0.986

AC attenuation correction, GM geometric mean, SD standard deviation

Table 2

Linear regression analysis between measure error of gastric residual y and patient age x ($n=122$)

Residual difference	Regression equation	R^2	P
Posterior – GM	$y = -0.565x + 1.676$	0.11	<0.001
Posterior AC – GM	$y = -0.124x + 1.64$	0.014	0.195

AC attenuation correction, GM geometric mean