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Comparison of Calculations to Estimate Gastric Emptying Half-Time of Solids in Humans

Alan R. Zinsmeister, Ph.D.[#], Adil E. Bharucha, M.B.B.S., M.D., and Michael Camilleri, M.D.
Clinical Enteric Neuroscience Translational and Epidemiological Research (CENTER)

[#]Department of Health Sciences Research, Division of Biomedical Statistics and Informatics,
Mayo Clinic, College of Medicine, Rochester, MN

Abstract

Background—Measuring solid gastric emptying (GE) at 4 hours is used to identify gastroparesis. GE half-time (GE $T_{1/2}$) is useful to assess overall and early GE.

Aim—To examine the validity of hourly imaging as a measurement of GE $T_{1/2}$ compared to estimates from more detailed imaging.

Methods—155 human subjects (99 female, 56 male) underwent scintigraphic GE of a solid-liquid meal. We calculated the GE $T_{1/2}$ using interpolation based on a full set of abdominal images obtained over 4 hours, and the GE $T_{1/2}$ based on images at 1, 2, 3, and 4 hours after the meal with linear interpolation of data.

Results—Differences in GE $T_{1/2}$ values (entire set of scan times compared to just the hourly scans) were small (overall median [5th, 95th %tiles] = −0.2[−7.5, 4.6] minutes) with slightly greater differences in males compared to females. The agreement between the two methods was very high [CCC (95%CI) = 0.993 [0.990, 0.995] and a Bland Altman plot indicated the variation in the results between the two methods did not change appreciably across the range of GE studied (within + 10 minutes for all but 4 subjects). Calculated GE $T_{1/2}$ values, omitting the 3h data from the hourly measurements, were associated with similar high accuracy overall and for fast GE, but were less accurate with slow GE.

Conclusion—Results of GE $T_{1/2}$ solids, using hourly imaging over 4 hours, are accurate in the range 75 to 235 minutes which reflects the typical range of GE of solids in health and disease.

Keywords

gastric emptying; scintigraphy; statistical analysis

The conventional test for measurement of gastric emptying is scintigraphy (1,2). Using a solid-phase meal is recommended, as it quantifies the emptying of a physiologic caloric meal. Most centers use a ^{99m}Tc sulfur colloid-labeled egg-containing meal with standard imaging at 0, 1, 2, and 4 hours. In fact, a 4-hour gastric emptying test, using radiolabeled

Address for correspondence: Michael Camilleri, M.D., Mayo Clinic, Charlton 8-110, 200 First St. S.W., Rochester, MN 55905, Tele: 507-266-2305, camilleri.michael@mayo.edu.

DISCLOSURES

The authors have no conflicts of interest.

AUTHORS' CONTRIBUTIONS

Dr. Zinsmeister: concept, data analysis, authorship of paper

Dr. Bharucha: investigator involved in acquisition of study data, authorship of paper

Dr. Camilleri: principal investigator, study concept, authorship of paper.

EggBeaters® with jam, toast, and water and measured by external scintigraphy, is advocated by the Society of Nuclear Medicine and The American Neurogastroenterology and Motility Society as the recommended standard (2). Assessment of gastric emptying over 4 hours is necessary, as extrapolation to measure $T_{1/2}$ may be erroneous (3).

Some regard the gastric retention of solids at 4 hours as the most reliable parameter for identifying gastroparesis. Gastric emptying $T_{1/2}$ (GE $T_{1/2}$) is also acceptable if imaging has been performed to 4 hours or at least to 50% emptying. However, it is also important to assess emptying at least 1 and 2 hours after radiolabeled meal ingestion, since prolongation of the early phases of emptying may also be associated with symptoms of gastroparesis, even though the gastric retention at 4 hours is normal or mildly delayed. Pharmacological studies have traditionally used GE $T_{1/2}$ as an endpoint of significant interest. Traditionally, estimation of GE $T_{1/2}$ has utilized detailed imaging over the 4-hour period or a power exponential analysis (4,5) which increases the cost of the procedure through the need for repeated imaging and special calculations. In the past, we have championed the use of hourly imaging for estimation of gastric emptying (6). The emptying phase of solids is generally linear after the initial lag phase, and gastroparesis due to neuropathic or myopathic motility disorders retards GE $T_{1/2}$ (5,7,8). Therefore, measurement of GE $T_{1/2}$ is a relevant clinical and pharmacodynamic measurement and, given the approximately linear post-lag phase, it is conceivable that imaging may be spaced out in time and still give accurate measurements of GE $T_{1/2}$.

We aimed to examine the validity of the use of hourly imaging (0-4 hours) as a measurement of GE $T_{1/2}$ compared to $T_{1/2}$ estimates obtained from more detailed imaging, every 15 minutes for the first 2 hours and every 30 minutes for the subsequent 2 hours.

MATERIALS AND METHODS

Study Design

The data used to develop these simpler mathematical models were obtained as part of studies previously performed in our laboratory in healthy human volunteers and patients with upper gastrointestinal symptoms. The study was approved by the Mayo Clinic Institutional Review Board prior to initiation. All included subjects met general research authorization requirements per Minnesota state law.

Method to Measure Gastric Emptying

The method, radiolabeled fat-containing, 296 kcal solid-liquid meal (2 scrambled eggs, 1 slice of bread and 240 mL of 1% milk [32% protein, 35% fat, 33% carbohydrate]), and conduct of the studies were described extensively in prior studies (9). One additional study (10) that was included to increase the number of patients with delayed gastric emptying had used a 200kcal, low-fat meal (4 oz. Eggbeaters®, 2 slices of white bread, jam and 120 mL water). This meal is recommended by national societies of nuclear medicine and neurogastroenterology and motility (2). In summary, images of the abdomen were obtained every 15 minutes for the first 2 hours, and every 30 minutes in the subsequent 2 hours.

Analysis of GE $T_{1/2}$

Three estimates of GE $T_{1/2}$, based on the proportions remaining in the stomach and obtained from the scintigraphically measured activity at each image scan time, were computed: first, linear interpolation using all the scan times over the 4-hour imaging sequence; second, linear interpolation using only imaging results at 1, 2, 3, and 4 hours; and third, linear interpolation of scans done at 1, 2, and 4 hours. This method linearly interpolates between the last point with >50% remaining vs. the first time point with <50% remaining.

Analysis

The three estimates of GE $T_{1/2}$ computed for each subject were summarized for the entire group, as well as for males and females separately. The agreement of the reduced scan time estimates (i.e. second and third versions) with the estimate using the full set of scan times was assessed using Lin's concordance correlation coefficient [CCC (11)] as well as visually using Bland Altman plots. Separate analyses were also performed for patients with fast (GE $T_{1/2}$ value <90 minutes based on full set of scan times) and slow gastric emptying GE ($T_{1/2}$ value ≥ 180 minutes based on full set of scan times).

RESULTS

The results for the three estimates of GE $T_{1/2}$ over the entire group and males and females separately are presented in Table 1: 21 participants had accelerated gastric emptying and 9 had delayed gastric emptying. There was excellent agreement of the GE $T_{1/2}$ estimates using the 4 hourly scans [CCC (95%CI) = 0.993 (0.990, 0.995) Figure 1, upper panel] and using just hours 1, 2, and 4 [CCC (95%CI) = 0.974 (0.965, 0.981) Figure 1, lower panel], with the GE $T_{1/2}$ estimate using all scan time points. Similar agreement was obtained for males and females separately (Table 1).

The corresponding Bland Altman plots (Figure 2, upper and lower panels), indicating the variation in the results between the full scan time estimate and each of the reduced scan time estimates, did not change appreciably across the range of GE studied [deltas within ± 10 minutes for all but 4 subjects]. For participants with slow GE ($T_{1/2}$ ≥ 180 minutes), the CCC (Table 1) for the hourly scans was excellent compared to the full complement of scan data; in contrast (Figure 3), there was a lower CCC for the calculated GE $T_{1/2}$ based on the scans at 1, 2, and 4 hours, suggesting that the hour 3 scan enhances accuracy for patients with delayed GE $T_{1/2}$. In Figure 3, note that the data for 3 of 9 participants are not as well matched as the other 6, which are close to the line of identity.

DISCUSSION

In this study, we wished to validate an easier method to calculate GE $T_{1/2}$ of solids during scintigraphic gastric emptying studies. We demonstrated virtually identical estimates based on reduced numbers of scan times. Avoiding fitting of power exponential models and reducing the number of images while retaining accuracy over a wide spectrum of gastric emptying values from 75 to 235 minutes are relevant to clinical practice and pharmacodynamic studies.

In summary, our data suggest that simple linear interpolation of the gastric emptying data obtained hourly over 4 hours after ingestion provides an accurate estimate of GE $T_{1/2}$. This has the potential to reduce costs and to obtain a relevant parameter that appraises the entire postprandial period, not only the proportion of the meal remaining in the stomach at 4 hours.

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Figure 1.

Linear correlation of the gastric emptying $T_{1/2}$ using 4 hourly images (total 5 images, Figure 1, upper panel) or images at 1, 2, and 4 hours (Figure 1, lower panel) and detailed imaging (13 total images) over 4 hours. Note the high degree of agreement between the estimates of $T_{1/2}$ in 155 individuals.

Figure 2.

Bland Altman plot showing the mean difference in calculated gastric emptying $T_{1/2}$ across the range of gastric emptying values when using either hourly imaging at 0-4 hours (Figure 2, upper panel) or images at 1, 2 and 4 hours (Figure 2, lower panel) compared to detailed imaging throughout the 4 hours (13 images). Note the y axes are different in Figure 2, upper and lower panels.

Figure 3.

Linear correlation of the gastric emptying $T_{1/2}$ using zero and 4 hourly images (total 5 images) or images at 0, 1, 2, and 4 hours (total 4 images) and detailed imaging (13 total images) over 4 hours in patients with slow gastric emptying. The interrupted line shows the line of identity. Note that three patients' data are not optimally estimated by the hourly scan calculation of $T_{1/2}$.

Table 1
Demographics of Participants and Gastric Emptying Data

Summary values are mean ($\pm$ SD) unless otherwise noted.

	Overall	Females	Males
N	155	99 (63.9%)	56 (36.1%)
Age, years	38($\pm$ 13)	39($\pm$ 12)	34($\pm$ 13)
BMI, Kg/m ²	27.6($\pm$ 5.1)	27.2($\pm$ 5.1)	28.4($\pm$ 5.0)
Proportion emptied at 4 hours	0.92($\pm$ 0.10)	0.91($\pm$ 0.10)	0.94($\pm$ 0.09)
GE T ½ (min): all scan times	120.6($\pm$ 31.4)	126.8($\pm$ 32.0)	109.6($\pm$ 27.3)
GE T ½ (min): hourly scan times	121.4($\pm$ 30.9)	127.3($\pm$ 30.8)	111.0($\pm$ 27.6)
GE T ½ (min): hours 1, 2, and 4	122.1($\pm$ 31.1)	127.9($\pm$ 30.8)	111.9($\pm$ 29.5)
Delta T ½ : all vs. Hourly	-0.80($\pm$ 3.73)	-0.47($\pm$ 4.09)	-1.38($\pm$ 2.92)
Delta T ½ : all vs. 1, 2, and 4 hours	-1.50($\pm$ 6.96)	-01.03($\pm$ 7.13)	-2.32($\pm$ 6.61)
CCC [95% CI] hourly vs. all	0.993 [0.990,0.995]	0.992 [0.987,0.994]	0.993 [0.988,0.996]
CCC [95%CI] 1, 2, and 4 hours vs. all	0.974 [0.965,0.981]	0.974 [0.961,0.982]	0.970 [0.950,0.982]
CCC [95%CI] Fast GE [†] (N=21; 12 males) hourly vs. all	0.963 [0.915,0.984]		
CCC [95%CI] Fast GE [†] (N=21) 1, 2, and 4 hours vs. all	0.963 [0.915,0.984]		
CCC [95%CI] Slow GE [§] (N= 9; 2 males) hourly vs. all	0.978 [0.915,0.995]		
CCC [95%CI] Slow GE [§] (N= 9; 2males) 1, 2, and 4 hours vs. all	0.520 [-0.136,0.859]		

CCC [95%CI] for slow and fast GE in each gender was not reported because of relatively small numbers of each gender

[†]GE T ½ value < 90 minutes (full set of scan times)

[§]GE T ½ value 180 minutes (full set of scan times)