Confirmation of Short Solid-Food Lag Phase by Continuous Monitoring of Gastric Emptying

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Reports on the existence of a lag phase before solid-food gastric emptying are conflicting. We studied solid-phase gastric emptying in ten normal-weight male subjects using two opposed cameras and continuous monitoring. Each ingested a 300-g meal containing ^{99m}Tc-labeled liver pate. Identical computer-interfaced cameras continuously monitored gastric activity from anterior and posterior projections. Lag phase was determined by three techniques: (1) inspection of the emptying curve; (2) time to a 2% decrease in stomach activity; and (3) the time of visual appearance of duodenal activity. A short lag phase time was found using all methods, averaging 8.6 min. We concluded that a short solid meal lag phase exists that can be missed with conventional radionuclide gastric emptying methods not employing continuous measurements.

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The purpose of this study was to examine the discrepancy in findings concerning the lag phase of gastric emptying of solid meals. Solid food must be ground into 1–2 mm particles before emptying through the pylorus can occur (*1*); therefore, solids would remain in the stomach until mixing occurred. Although some authors describe a lag phase prior to the beginning of solid food emptying from the stomach (*2–6*), others do not (*7–10*). In addition, the method of lag phase measurement has varied and many of these methods use a different definition of lag phase.

Accurate quantitative measurements of gastric emptying can be difficult to obtain. Not applying correction for the changes in body depth of the meal during emptying, for example, can create a false increase in anterior stomach counts after meal ingestion caused by the anterior shift of tracer as it moves from the fundus into the antrum. Gamma ray attenuation as a function of source depth within the body decreases exponentially as activity moves away from one camera position, and increases as that activity approaches the opposing camera position. Using only one camera can therefore produce an artifactual lag phase, when, in fact, emptying has occurred (*11*). Correcting the data, using the geometric mean of the anterior and posterior counts, prevents the apparent increase in stomach activity. The geometric mean can be calculated by taking the square root of the product of the anterior and posterior counts; this produces a measurement of stomach activity independent of source depth within the body. Less than 2% variation in source activity is observed with changes in source position (*12–14*).

To accurately detect the presence of a lag phase, we employed the following critical criteria: (1) anterior/posterior geometric mean imaging; (2) continuous data sampling; (3) upright seated posture; and (4) use of a stable solid tracer and suitable meal composition. We undertook a study to determine if a lag phase component existed employing these techniques.

MATERIALS AND METHODS

Subjects

This investigation was approved by the Institutional Review Board of the University of Utah. Informed consent was obtained from the ten healthy volunteers participating. Subjects were normal-weight males with no history of gastrointestinal disease and who were not taking medications known to alter gastrointestinal motility.

Tracer and Meal

Sulfur colloid-labeled pate was prepared by adding 5 mCi of ^{99m}Tc-sulfur colloid to 50 g of canned liver pate. This mixture was placed in a hot frying pan and stirred occasionally while frying for 10–15 min to produce 2–5 mm particles. The mixture was then dried on an absorbent towel. The in vitro and in vivo stability of labeled pate is equal to that of intracellular-labeled chicken liver (*15*). The 300-g test meal consisted of 150 g beef stew, containing 600 μCi of ^{99m}Tc-sulfur colloid-labeled pate, and 150 g orange juice; total caloric content was 208 kcal.

Imaging Techniques

The subjects sat on tall laboratory stools in a modified sitting/standing position between two identical scintillation cameras (Model 420, Technicare Inc, Cleveland, Ohio) interfaced to two computers. Point-source markers of ^{99m}Tc were taped to the abdomen both anteriorly and posteriorly to allow monitoring and correction of any motion which might occur during the study. Sequential images were obtained at 30-sec intervals beginning with the onset of meal ingestion and continuing for 2 hr after meal completion.

The sequence of images was analyzed and corrected for any

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patient motion during the study by examining the location of the reference point-source positions and stomach. A composite image of the 2-hr study was generated for the anterior and posterior image sets and a region of interest was manually assigned for the total stomach. Anterior and posterior time-activity curves were generated beginning at the time of meal completion. These curves were corrected for camera sensitivity as measured for each individual study. Curves were corrected for radioactive decay and the geometric mean of the anterior and posterior counts was calculated.

Data Analysis

Three techniques were selected to measure the onset of emptying from the stomach to identify and quantitate a lag phase: (1) visual inspection of the final curve for each patient was subjectively analyzed to identify the time of onset of a decrease in stomach activity; (2) a lag time was quantitatively determined as the time at which a 2% decrease from maximal curve activity was measured; and (3) the time of visual appearance of duodenal radioactivity was determined on enhanced computer images.

TABLE 1
Gastric Lag Phase study

Subject	Visual curve inspection (min)	2% curve decrease (min)	Duodenal appearance (min)	Subject mean (min)
1	8.0	11	10.0	9.6
2	12.0	15	16.0	14.3
3	6.0	7	4.0	5.6
4	10.0	10	6.0	8.6
5	8.0	6	10.5	8.1
6	4.0	12	7.5	7.8
7	8.0	12	4.5	8.1
8	8.5	10	4.0	7.5
9	14.0	14	4.5	10.8
10	4.5	6	7.0	5.8
mean	8.3	10.3	7.4	—
± s.d.	3.11	3.16	3.83	—

RESULTS

All subjects consumed the standard meal in less than 7 min. The time of meal completion was taken as time zero and data during meal consumption were discarded. Figure 1 shows an example of the geometric mean corrected emptying curve from one subject.

Table 1 contains the individual subject lag time measurements and means for each technique along with the mean results for each measurement technique. By visual inspection of the emptying curve, we observed a mean lag time of 8.3 min with a range of 4–14 min. Analysis of the point at which a 2% drop in activity appeared gave a mean lag time of 10.3 min with individual measurements ranging from 6–14 min. The appearance of duodenal activity showed a mean lag time of 7.4 min with a range of 4–16 min. The average lag time of all subjects for each lag measurement technique was 8.6 ± 2.52 min.

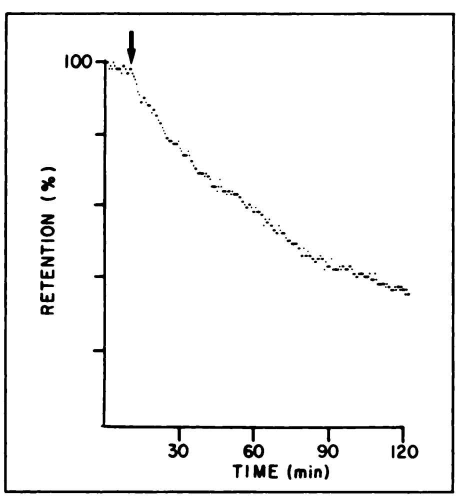

FIGURE 1. Gastric emptying data using continuous measurements and geometric mean correction demonstrating a lag period (arrow) prior to the onset of emptying in this subject.

The average half-emptying time was 78.4 ± 27.35 min and ranged from 43–119 min. These half-emptying time values were within normal limits for our laboratory.

DISCUSSION

Our study confirms the presence of a short lag phase prior to the beginning of gastric emptying. Our three techniques for lag time measurement gave similar results, indicating that our data were not biased, which may occur if only one measurement technique had been used.

In 1951, Hunt and Spurrell utilized a 750-ml pectin liquid meal and identified that liquid emptying in 21 subjects was described by a mono-exponential curve (*16*). They reported that some subjects had a range of the onset of emptying defined as a "starting index" time of −17.3 to +13.6 min, with the mean of −0.05 min and standard deviation of ±9.6 min. With liquid meals, there was an individual "starting index" time variation but no definite distinction of a lag period prior to emptying as a group. A similar study of 336 meals published in 1984 by Smith et al. (*17*), did not identify a lag period with liquid meals.

Due to the inherent particulate nature of solid food and the antropyloric discrimination of liquids and solids (*1*, *18*), a lag period for solid food emptying would be greater than that of liquids. However, review articles on scintigraphic techniques of gastric emptying have not described a solid meal lag time (*7*,*8*).

The first report of a radioisotopic method to measure solid food emptying was reported by Griffiths in 1966 (*19*). Using a dual-probe rectilinear scanner, serial scans were obtained and a combination of anterior and posterior counts were used to measure the rate of solid food emptying. A linear pattern of emptying was observed without a lag period prior to the onset of emptying. In 1976, Scarpello et al. did not observe a solid meal lag period in 19 control subjects (*9*). They used an "ordinary" meal with anterior only imaging using a scintillation camera and computer.

Collins et al. (*4*) reported a solid-phase lag time of 21 ± 2 (s.e.m.) min in 11 normal subjects, using a small meal of 100 g ground beef (270 kcal) and 150 ml water or dextrose. The subjects were continuously imaged from the posterior projection with a lateral image attenuation correction technique. Their lag time was determined by evaluating the solid phase curve and noting the time prior to a decrease in counts. Using a similar analysis technique, we identified the time at which a 2% drop in stomach activity occurred to be somewhat shorter (10.3 ± 3.16 min) than Collins et al. In Collins' study, patients were in the sitting position, which may have increased the delay in emptying. Patient posture has been documented to play a role in gastric emptying (*20,21*), as does meal composition, sex, exercise and a variety of other factors (*10,22, 23*). In addition, the lateral image attenuation correction technique is not as frequently employed or accepted as compared to the geometric mean correction technique (*5, 10–15,20,21*).

Using a beef stew meal (225 kcal), Loo et al. (*5*) noted a starting time of emptying of 23.7 ± 26.7 min in 12 control subjects. They imaged anteriorly and posteriorly and used geometric mean corrections at 5-min intervals. The delay period they used was a starting index defined as the intersection of a second linear curve and the 100% retention value. Since some emptying beings during the first linear curve component, their starting index value did not represent the onset of emptying. They also reported that 12 of 88 studies demonstrated a negative starting index, meaning the first bilinear component was more rapid than the second. These data reveal limitations of lag time measurements as determined by this technique.

Horowitz et al. (*3*) reported a lag time followed by a linear emptying pattern of solid meals using a posterior view sitting position and lateral view attenuation method. They measured a mean lag time of 35 min (range 9–69 min) in 22 normal subjects. MacGregor et al. (*2*) observed a short delay in three of five normal subjects using only anterior imaging.

In a recent study of meal energy content on gastric emptying, Velchik et al. observed linear patterns of emptying and measured a 20-min meal retention time in three different meals of varying caloric density (*24*). They performed 32 studies on 12 volunteer subjects using anterior and posterior geometric mean corrected data and 15-min intervals between images. Although data corrections are employed, the 15-min frequency of imaging may have been too long to accurately assess a short lag period to the onset of emptying.

Velchik's technique (*25*) measures the time to when the second derivative of a modified power function equals zero, which they define as a lag phase index. This index identifies a delay period for power function presented data and does not measure the time to the first onset of emptying. We have used anterior and posterior geometric mean correction techniques to measure solid meal emptying rates (*10*). Our studies of large meals have consistently shown a linear pattern of solid food emptying without evidence of a lag period; however, our images in that study were not acquired continuously and a short lag period might have been missed.

The power function has been proposed as a method that would better express the shape characteristics of a gastric emptying curve by using two values, the first, power value, to identify lag, and the second, half-emptying time, to describe the rate of decrease (*26*). Siegel et al. (*25*) reported a modified power function exponential B value of 1.54 in data acquired anteriorly in supine subjects without appropriate correction techniques. Non-geometric mean corrected data may create artifactual patterns causing complex curve shapes and may create an apparent or prolonged lag before emptying (*11,12*).

In conclusion, we have incorporated several basic requisite criteria to accurately evaluate the presence of a gastric emptying lag phase. Combining three techniques gave us similar results with an average lag phase of 8.6 min. We conclude that a short solid phase lag time to the onset of emptying exists, which can be missed with conventional gastric emptying imaging techniques that do not employ continuous measurements.

REFERENCES

1. Meyer JH, Ohashi H, Jehn D, Thompson JB. Size of liver particles emptied from the human stomach. *Gastroenterology* 1981;80:1489–1496.
2. MacGregor IL, Martin P, Meyer JH. Gastric emptying of solid food in normal man and after subtotal gastrectomy and truncal vagotomy with pyloroplasty. *Gastroenterology* 1977;72:206–211.
3. Horowitz M, Maddox A, Harding PE, et al. Effect of cisapride on gastric and esophageal emptying in insulin-dependent diabetes mellitus. *Gastroenterology* 1987;92:1899–1907.
4. Collins PJ, Horowitz M, Cook DJ, Harding PR, Shearman DJC. Gastric emptying in normal subjects—a reproducible technique using a single scintillation camera and computer system. *Gut* 1983;24:1117–1125.
5. Loo FD, Palmer DW, Soergel KH, Kalbfleisch JH, Wood CM. Gastric emptying in patients with diabetes mellitus. *Gastroenterology* 1984;86:485–494.
6. Camilleri M, Malagelada JR, Brown ML, Becker G, Zinsmeister AR. Relation between antral motility and gastric emptying of solids and liquids in humans. *Am J Physiol* 1985;249:580–585.
7. Malmud LS, Fisher RS, Knight LC, Rock E. Scintigraphic evaluation of gastric emptying. *Semin Nucl Med* 1982;XII:116–125.
8. Minami H, McCallum RW. Physiology and pathophysiology of gastric emptying in humans. *Gastroenterology* 1984;86:1592–1610.
9. Scarpello JHB, Barber DC, Hague RV, Cullen DR, Sladen GE. Gastric emptying of solid meals in diabetics. *Br Med J* 1976;2:671–673.
10. Moore JB, Christian PE, Coleman RE. Gastric emptying of varying meal weight and composition in man. Evaluation by dual-liquid and solid-phase isotopic method. *Dig Dis Sci* 1981;26:16–22.
11. Moore JG, Christian PE, Taylor AT, Alazraki N. Gastric emptying measurements: delayed and complex emptying patterns without appropriate correction. *J Nucl Med* 1985;26:1206–1210.
12. Tothill P, McLoughlin GP, Heading RC. Techniques and errors in scintigraphic measurements of gastric emptying. *J Nucl Med* 1978;19:256–261.
13. Ferrant A, Cauwe F. Quantitative organ-uptake measurement with a gamma camera. *Eur J Nucl Med* 1979;4:223–229.
14. Christian PE, Moore JG, Sorenson JA, Coleman RE, Welch DM. Effects of meal size and correction technique on gastric emptying time: studies with two tracers and opposed detectors. *J Nucl Med* 1980;21:883–885.

15. Christian PE, Moore JG, Datz FL. Comparison of Tc-99m-labeled liver and liver pate as markers for solid-phase gastric emptying. *J Nucl Med* 1984;25:364–366.
16. Hunt JN, Spurrell WR. The pattern of emptying of the human stomach. *J Physiol* 1951;113:157–158.
17. Smith JL, Jiang CL, Hunt JN. Intrinsic emptying of the human stomach. *Am J Physiol* 1984;246:R959–R962.
18. Malagelada JR, Longstreth GF, Summerskill WHJ, Go VLW. Measurement of gastric functions during digestion of ordinary solid meals in man. *Gastroenterology* 1976;70:203–210.
19. Griffith GH, Owen GM, Kirkman S, Shields R. Measurement of rate of gastric emptying using chromium-51. *Lancet* 1966;1:1244–1245.
20. Tothill P, McLoughlin GP, Holt S, Heading RC. The effect of posture on errors in gastric emptying measurements. *Phys Med Biol* 1980;25:1071–1077.
21. Moore JG, Datz FL, Christian PE, Greenberg E, Alazraki N. Effect of body posture on radionuclide measurements of gastric emptying. *Dig Dis Sci* 1988;33:1592–1595.
22. Datz FL, Christian PE, Moore J. Gender-related differences in gastric emptying. *J Nucl Med* 1987;28:1204–1207.
23. Moore JG, Datz FL, Christian PE. Exercise increases solid meal gastric emptying rates in men. *Dig Dis Sci* 1990;35:428–432.
24. Velchik MG, Reynolds JC, Alavi A. Effect of meal energy content on gastric emptying. *J Nucl Med* 1989;30:1106–1110.
25. Siegel JA, Urbain JL, Adler LP, et al. Bi-phasic nature of gastric emptying. *Gut* 1988;29:85–89.
26. Elashoff JD, Reedy TJ, Meyer JH. Analysis of gastric emptying data. *Gastroenterology* 1982;83:1306–1312.

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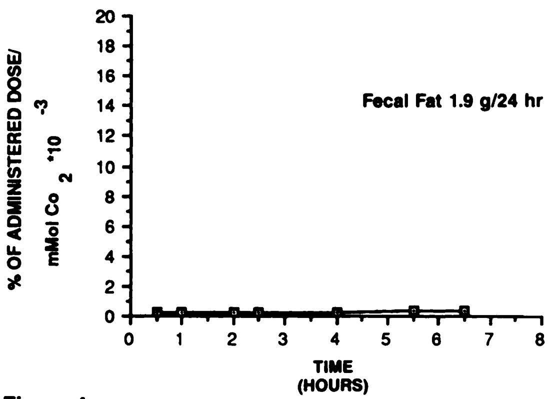

Figure 4

Several modifications of the imaging technique for identifying ectopic gastric mucosa have been proposed. For each of the following scintigraphic results (items 5–7), select the intervention most likely to produce it (options A–E).

A. nasogastric suction
B. pretreatment with perchlorate
C. pretreatment with cimetidine
D. pretreatment with pentagastrin and glucagon
E. pretreatment with pentagastrin

5. No change in ^{99m}Tc uptake by ectopic gastric mucosa and reduction of abdominal background activity
6. Increased ^{99m}Tc uptake by ectopic gastric mucosa and reduced release of ^{99m}Tc into the bowel
7. Increased ^{99m}Tc uptake by ectopic gastric mucosa and reduced translocation of tracer

SELF-STUDY TEST
Gastrointestinal Nuclear Medicine
ANSWERS

ITEMS 1–4: Bile Salt Breath Testing in Patients with Malabsorption

ANSWERS: 1, D; 2, C; 3, B; 4, A

The curves in Figures 1–4 are adapted from similar data reported by Sherr et al. Control subjects with normal absorptive function (24-hr fecal fat < 6.0 g) show only a mild increase in $^{14}CO_2$ excretion 4–6 hr after food intake, with a mean total $^{14}CO_2$ excretion of 2.2% ± 0.6% of the administered dose. The results in Figure 4 are those of a normal subject. Patients with pancreatic insufficiency have increased fecal fat excretion, but no increase in bile salt breakdown (Fig. 3). Patients with bacterial overgrowth in the small intestine have $^{14}CO_2$ curves similar to those of patients with ileal resection with a rapid early rise in $^{14}CO_2$ exhalation. In the studies performed by Sherr et al., the mean total $^{14}CO_2$ excretion in 6 hr (31.4% ± 4.6%) and peak excretion (18.8% ± 2.6%) tended to be higher for patients with ileal resection than for those with bacterial overgrowth. Fat content is also higher (27.8 g) with resection compared with the patients with bacterial overgrowth. Hence, the results shown in Figure 2 are more characteristic of patients with ileal resection, and those in Figure 1 are more typical of patients with bacterial overgrowth syndromes.

Patients with fish tapeworm (*Diphyllobothrium latum*) infestation develop vitamin B_{12} deficiency because of competition by the parasite for vitamin B_{12} in ingested food. The bile-salt breath test would be normal in this disorder, although fecal fat excretion could be increased if secondary malabsorption developed due to the effects of vitamin B_{12} deficiency on the intestinal mucosa itself. However, these tests cannot be used to confirm the diagnosis of fish tapeworm infestation.

References

1. Beck WS. The megaloblastic anemias. In: Williams WJ, Beutler E, Erslev AJ, Lichtman MA, eds. *Hematology*, 3rd ed. New York: McGraw-Hill, 1983:434–465.
2. Sherr HP, Sasaki Y, Newman A, Banwell JG, Wagner HN Jr, Hendrix TR. Detection of bacterial deconjugation of bile salts by convenient breath-analysis technique. *N Engl J Med* 1971;285:656–661.

ITEM 5–7: Interventions in Meckel's Diverticulum Scintigraphy

ANSWERS: 5, A; 6, C; 7, D

Several different interventions have been proposed to enhance imaging of ectopic gastric mucosa. Nasogastric suction has been utilized to enhance imaging by removing secreted ^{99m}Tc activity from the stomach and reducing the background activity. Perchlorate decreases uptake of [^{99m}Tc]pertechnetate by gastric mucosa and will reduce the sensitivity of [^{99m}Tc]pertechnetate scanning for detecting ectopic gastric mucosa. Cimetidine has been shown to enhance imaging of ectopic gastric mucosa by causing a continued accumulation of [^{99m}Tc]pertechnetate in gastric mucosa and by reducing the release of tracer into the surrounding bowel. Animal studies have shown that pentagastrin will cause increased uptake of [^{99m}Tc]pertechnetate by gastric mucosa but, when used alone, there is also increased accumulation of tracer in the small bowel, and this may impair scintigraphic detection of ectopic gastric mucosa. When used in conjunction with the antiperistaltic agent, glucagon, the translocation of tracer into the small bowel is reduced and imaging for ectopic gastric mucosa is enhanced.

References

1. Petrokubi RJ, Baum S, Rohrer GV. Cimetidine administration resulting in improved pertechnetate imaging of Meckel's diverticulum. *Clin Nucl Med* 1978;3:385–388.
2. Sfakianakis GN, Anderson GF, King DR, Boles ET Jr. The effect of gastrointestinal hormones on the pertechnetate imaging of ectopic gastric mucosa in experimental Meckel's diverticulum. *J Nucl Med* 1981;22:678–683.