The Effect of Meal Energy Content on Gastric Emptying

Michael G. Velchik, James C. Reynolds, and Abass Alavi

Division of Nuclear Medicine, Department of Radiology and Division of Gastroenterology, Department of Medicine, Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania

Gastric emptying (GE) has been reported to be influenced by meal weight (grams) and composition (% carbohydrate:protein:fat) but the effect of meal energy content (kcal) on gastric emptying, independent of composition, has not been thoroughly investigated by scintigraphic techniques. In order to determine the effect of caloric content on GE, 12 normal male volunteers, ranging in age from 19–28 yr (mean = 24 yr), had GE scans (n = 32) performed with a solid meal of fixed composition (carbohydrate 40%:protein 40%:fat 20%) but varying energy content [150 kcal (n = 9), 300 kcal (n = 14), and 600 kcal (n = 9)]. Increasing the energy content of the meal of fixed composition progressively delayed gastric emptying: $T_{1/2}$ = 57′, 70′, and 95′ for 150 kcal, 300 kcal and 600 kcal, respectively ($p < 0.05$; Student's t-test). Reproducibility, evaluated by performing GE scans (n = 8) on different days in the same individual (n = 4) with the same meal (300 kcal), was good ($r \geq 0.89$). Variability varied inversely with meal energy content (CV:150 kcal ≥ 300 kcal and 600 kcal). The 300 kcal mean seems to be the best compromise since it results in less intersubject variability than 150 kcal, has minimal intrasubject variability, but is not as prohibitively large as the 600 kcal meal.

J Nucl Med 30:1106–1110, 1989

Although the physiology of gastric emptying has been extensively investigated, many unanswered questions still remain. In addition to various disease states such as diabetes, peptic ulcer disease, cancer, and surgery, gastric emptying may be influenced by emotional state, hormones, drugs, and the nature of the ingested meal itself. The meal phase (liquid vs. solid), composition (carbohydrate: protein: fat), weight, and energy density (kcal/g) have been reported to affect the rate of gastric emptying. However, the latter has not been thoroughly investigated independent of composition by radionuclide techniques.

Radionuclide scintigraphy, first introduced by Griffith et al. (*1*) in 1966, has emerged as the best noninvasive technique for quantitating gastric emptying. A major limitation of this method that pervades the literature and diminishes its universal application is its lack of standardization with regard to a uniformly feasible among different labs. It is well known that the accepted optimal meal of specific composition that would make results interchangeable and comparison composition of the meal affects gastric emptying (*2–8*). Therefore, each laboratory has established its own normal range of gastric emptying for a meal of a given composition. This has necessarily resulted in a wealth of inconsistent and confusing published data that cannot be strictly compared among different institutions. An abbreviated menu of some of the meals that have been employed include porridge (*1*), beef stew (*9*), chicken liver (*10*), egg (*11,12*), cottage cheese (*13*), fiber (*14*), and resin (*15*).

Alternatively, it may be desirable if the phase, composition, weight, volume, and energy density of an "ideal" meal could be defined and adopted by all labs. The ideal meal should be practical, easy to prepare, palatable, easy to consume, readily available, have a high radionuclide labeling efficiency and stability in acid medium, yield reproducible results with minimal variation among normals and maximum separation between normals and abnormals. We conducted this study in order to investigate the effect of meal caloric content on gastric emptying rate independent on other

Received Aug. 19, 1988; revision accepted Jan. 24, 1989.

For reprints contact: Michael G. Velchik, MD, Div. of Nuclear Medicine, Dept. of Radiology, Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania.

variables and to perhaps better define the optimal meal with respect to caloric content.

METHODS AND MATERIALS

The study population consisted of 12 normal (by history and physical examination) nonsmoking male volunteers, ranging in age from 19–28 yr (mean = 24 yr). Criteria for exclusion included: (a) a history of gastritis, gastrointestinal ulcers, or other GI dysfunction, (b) a history of diabetes, (c) consumption of any drugs within the preceding 4 days, (d) a history of mental illness, and/or (e) hypo- or hyperparathyroidism. All medications were discontinued 4 days prior to and during the study. Informed written consent was obtained and the study was approved by the Radiation Safety Office and the Committee on Studies Involving Human Beings.

Thirty two radionuclide gastric emptying studies were performed in the 12 subjects with a solid meal of fixed composition (carbohydrate 40%:protein 40%:fat 20%) but varying energy content [150 kcal (n = 9), 300 kcal (n = 14), and 600 kcal (n = 9)]. Six subjects had all three types of kcal meals and four subjects had repeat studies with the 300 kcal meal to evaluate reproducibility.

The 150 kcal meal consisted of 300 μCi technetium-99m (^{99m}Tc) sulfur colloid bound to 124 g egg white, 20 g white bread, 3 g butter, in the form of an egg sandwich (total weight = 147 g; energy density = 1.02 kcal/g) and 180 ml of deionized water (total meal energy density = 0.46 kcal/g). This was doubled for the 300 kcal meal and quadrupled for the 600 kcal meal. Thus, all three meals had the same composition and energy density, but progressively increasing total energy content and necessarily volume.

Images of 1 min duration were obtained in the anterior and posterior erect projections with a large field-of-view gamma camera equipped with a low-energy, all purpose collimator interfaced to a computer (GE Star II) at 15-min intervals for 2 hr with the patient in the erect position (sitting or standing). The subjects were permitted to sit or move around ad lib in between imaging.

The geometric mean counts (anterior counts × posterior counts)$^{1/2}$ were calculated for each 15-min interval after correction for radioactive decay by generating a stomach region of interest for each image. The percent gastric retention was calculated for each 15-min interval as (decay corrected geometric mean counts at t = 0)/(geometric mean counts at t = 0) × 100.

RESULTS

Increasing the energy content of a meal of fixed composition resulted in a progressive delay in gastric emptying T½ = 57′ for 150 kcal, T½ = 70′ for 30 kcal, and T½ = 95′ for 600 kcal that was a significant ($p \leq 0.05$) difference among all groups (Fig. 1). The percent gastric emptying at 1 hr was 54% ± 7 (mean ± s.e.), 41% ± 3, and 31% ± 4 for the 150, 300, and 600 kcal means, respectively. This reached statistical significance (Student's t-test) only for the 150 versus 600 kcal meal ($p \leq 0.01$). The percent gastric emptying at 2 hr was 86% ± 5 (mean ± s.e.), 77% ± 4, and 61% ± 2 for the 150, 300, and 600 kcal meals, respectively. This reached statistical significance was 150 versus 600 ($p \leq 0.005$) and 300 versus 600 ($p \leq 0.025$) but not for 150 versus 300 ($0.05 < p < 0.1$).

A progressive elevation and shift from left to right in the gastric emptying curves with increasing meal energy content is evident in Figure 1. Analysis of the "area under the curve" reveals a progressive increase in area with increasing meal caloric content: 300 kcal Curve Area = 120% × 150 kcal; 600 kcal Curve Area = 135%

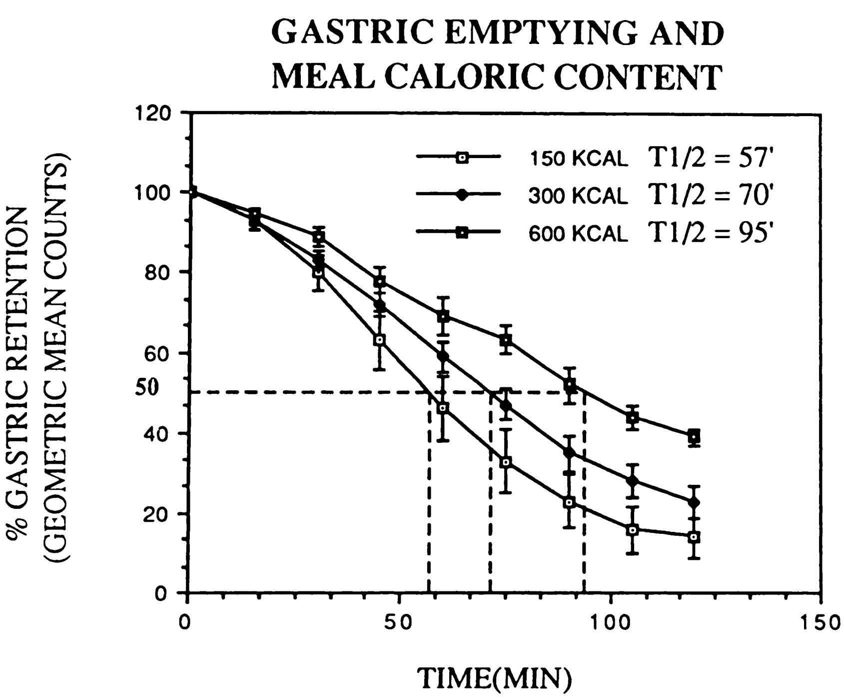

FIGURE 1
Graph depicting the progressive delay in gastric emptying as a result of increasing meal energy content but fixed composition. (I = s.e.m.).

× 300 kcal. There was no significant difference in the lag phase (16) for the three meals of different energy content (mean = 20 min) but analysis of the slope of the emptying portion of the curves obtained a progressive decrease in slope with increasing meal energy content: slope = −1.0, −0.83, and −0.5 for the 150, 300, and 600 kcal meals, respectively, indicating that the delay was due to slowing of the emptying phase and independent of the lag phase.

The variability of the data within an energy category was inversely proportional to the meal energy content being greatest for the 150 kcal meal and least with the 600 kcal meal. The average s.e., s.d., and coefficient of variation (CV) values for the 150, 300, and 600 kcal meals were as follows: SE = 5.8, 3.3, 2.9; SD = 17.5, 12.5, 8.6; CV = 60.6, 31.9, and 14.3, respectively.

The reproducibility of results with the 300 kcal meal was evaluated in four subjects by performing GE scans on different days with an interscan interval of 4 days (n = 2), 1 wk (n = 1), 1 mo (n = 1), and 5 mo (n = 1). The correlation coefficients (r) were 0.985, 0.888, 0.995, and 0.982, respectively. Thus, the reproducibility was good r ≥ 0.888 (Fig. 2). Measurement of blood and urine radioactivity in several subjects at 1 and 2 hr postcibally showed no significant increase in radioactivity over background levels indicating good stability of

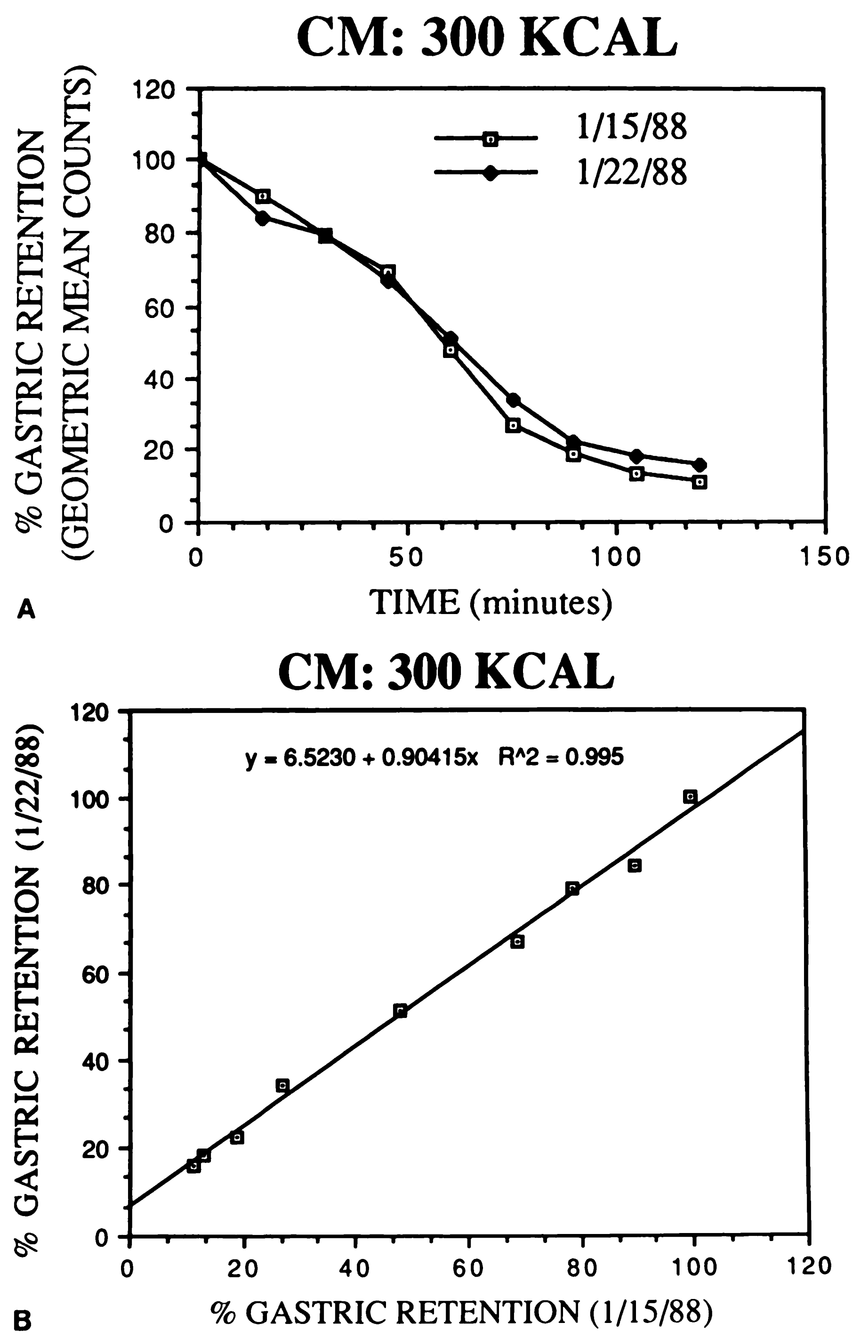

FIGURE 2
Good reproducibility (r = 0.995) demonstrated in one patient on two different days 1 wk apart with the 300 kcal meal.

the radiopharmaceutical preparation with no significant dissociation or absorption of technetium.

DISCUSSION

Delayed transit of foodstuffs through the gastrointestinal tract is a major cause for patients to seek medical attention. A number of diseases affect gastric emptying including diabetes, peptic ulcer disease, gastric cancer, gastric surgery, scleroderma, amyloidosis, achalasia, and various drugs. Frequently, patients present with abdominal pain and bloating for which no specific etiology is found. These patients are often given a presumptive diagnosis of exclusion termed "spastic bowel" or "non-ulcer dyspepsia". Perhaps just as important as the diagnosis is the development of specific methods to quantitate the severity of GI dysmotility and the response to medical or surgical therapy.

Radionuclide scintigraphy, being noninvasive, readily available, quantitative and physiological, has emerged as the optimal method for the evaluation of gastric emptying. Intubation techniques are invasive, impractical, nonphysiological, limited to the liquid phase, and have poor patient acceptance. Although the radiographic upper GI series exquisitely displays anatomic detail, it also is nonphysiological and not quantitative.

As previously emphasized, if radionuclide techniques are employed to quantitate gastric emptying, it is crucial that each laboratory define its own normal limits for a specific meal composition. We have already described the characteristics of an ideal meal. We have chosen a technetium-99m-labeled egg sandwich of a sulfur colloid ([^{99m}Tc]SC) composition typical of the American diet (CHO 40%: PR 40%: FAT 20%) because it is readily available, inexpensive, easy to prepare (with a high labeling efficiency and stability), and is palatable (especially for breakfast since most of our studies are performed in the morning). We (*12*) and others (*17*) have previously demonstrated a high labeling efficiency (93%) and stability (97.4%) in acid medium of [^{99m}Tc] SC bound to egg albumin.

We have imaged in both the anterior and posterior projections (geometric mean method) since other investigators have demonstrated that imaging in the anterior projection alone may underestimate gastric emptying by as much as 20% because of attenuation correction errors related to the posterior to anterior movement of stomach contents from the fundus to the antrum (*18*). Independent analysis of our gastric emptying data from only the anterior projection confirmed this claim. Patient position has also been shown to influence gastric emptying (*19*) and we have adopted the erect position since it is the most physiologic. By keeping meal composition constant we have attempted to determine the effect of meal energy content on gastric emptying and to determine the optimal meal caloric content in order to minimize interpatient variability and maximize reproducibility.

Gastric emptying is influenced by emotional state, neurological factors (sensory/motor), and endogenous hormones (principally gastrin, secretin, and cholecystokinin). These factors contribute to the regulation of gastric emptying and cannot be independently controlled. Meal phase affects emptying. The emptying of liquids is monoexponential and is predominantly controlled by the fundus and body. Solids empty more slowly in a linear fashion determined by the antrum and duodenopyloric mechanism.

Several investigators have shown that increasing meal weight delays gastric emptying (*3,4,10,11,20*). McHugh et al. (*2*), reported that gastric emptying is progressively delayed by increasing caloric density of liquids in rhesus monkeys. Moore et al. (*3*) found a delay in gastric emptying with increasing meal caloric content in human subjects, however meal composition (% CHO:PR:FAT) was not held constant. Hunt et al. (*5*) compiled data from the literature and concluded that increasing meal nutritive density delays gastric emptying for meals of different composition. We have demonstrated a delay in gastric emptying for meals of identical composition but increasing energy content. We did not strictly control for meal volume (in order to keep meal composition and energy density constant while progressively increasing total meal energy content, volume must necessarily increase), however Hunt (*5*) showed that meal nutritive density determines the rate of gastric emptying independent of the initial meal volume and postulated that regulation occurred via duodenal receptors sensitive to the osmotic effects of the digestion products of dietary carbohydrates and proteins and the surface-tension lowering effect of soaps formed by digested fats (*5,6*). Fisher et al. (*21*) have found an indirect rather than direct relationship between meal volume and rate of gastric emptying. However, Siegel et al. (*16*) demonstrated a delay in gastric emptying with increasing meal volume predominantly due to a prolongation of the lag phase. Our data show a progressive delay in gastric emptying with increasing meal energy content and volume despite constant meal composition and energy density.

We have added further support to the energy/volume dependence of gastric emptying independent of meal composition and density. Although the statistical results of the 600 kcal meal compared favorably with the 300 kcal meal, its volume was prohibitively excessive; consequently many subjects had difficulty finishing the meal within a reasonable period of time. We suggest that a 300 kcal meal of the composition CHO 40%:PR40%:FAT20% is the best compromise with respect to practicality (meal volume), the reduction of variance (facilitating maximum separation of normals from abnormals) and the maximization of reproducibility.

REFERENCES

1. Griffith GH, Owen GM, Kirkman S, et al. Measurement of rate of gastric emptying using chromium-51. *Lancet* 1966; 1:1244–1245.
2. Mchugh PR, Moran TH. Calories and gastric emptying: a regulatory capacity with implications for feeding. *Am J Physiol* 1979; 363:R254–260.
3. Moore JG, 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.
4. Christian PE, Moore JG, Sorenson JA, Coleman RE, Weich DM. Effects of meal size and correction technique on gastric emptying time: studies with two tracers and opposed detectors. *J Nucl Med* 1980; 21:833–885.
5. Hunt JN, Stubbs DF. The volume and energy content of meals as determinants of gastric emptying. *J Physiol* 1975; 245:209–225.
6. Hunt JN, Cash R, Newland P. Energy density of food, gastric emptying, and obesity. *Am J Clin Nutrition* 1978; 31:S259–260.
7. Hunt JN. Mechanisms and disorders of gastric emptying. *Ann Rev Med* 1983; 34:219–229.
8. Collins PJ, Horowitz M, Cook DJ, Harding PE, Shearman DJC. Gastric emptying in normal subjects—a reproducible technique using a single scintillation camera and computer system. *Gut* 1983; 24:1117–1125.
9. Pellegrini CA, Broderick WC, Van Dyke D, Way LW. Diagnosis and treatment of gastric emptying disorders clinical usefulness of radionuclide measurements of gastric emptying. *Am J Surg* 1983; 145:143–151.
10. Meyer JH, Macgregor MB, Gueller R, et al. Tc-99m-tagged chicken liver as a marker of solid food in the human stomach. *Am J Dig Dis* 1976; 21:296–304.
11. 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.
12. Kropp HS, Long WB, Alavi A, Hansell JR. Effect of water and fat on gastric emptying of solid meals. *Gastroenterology* 1979; 77:797–1000.
13. Norris FS. Method of technetium-99m tagging of cottage cheese for gastrointestinal motility studies. *J Nucl Med* [Abstract] 1983; 24:P99.
14. Malagelada JR, Carter SE, Brown ML, Carlson GL. Radiolabeled fiber a physiologic marker for gastric emptying and intestinal transit of solids. *Dig Dis Sci* 1980; 25:81–87.
15. Kim EE, Choy YC, Domstad PA, et al. Biologic gastric emptying time using Tc-99m TETA polystyrene resin in various clinical conditions. *Eur J Nucl Med* 1981; 6:155–158.
16. Siegel JA, Urbain JL, Adler LP, et al. Biphasic nature of gastric emptying. *Gut* 1988; 25:85–89.
17. Knight LC, Malmud LS. Technetium-99m ovalbumin labeled eggs: comparison with other solid food markers in vitro. *J Nucl Med* 1981; 22:28.
18. Tothill P, McLoughlin GP, Heading RC. Techniques and errors in scintigraphic measurements of gastric emptying. *J Nucl Med* 1978; 19:256–261.
19. 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.
20. Heading RC, Tothill P, McLoughlin GP, et al. Gastric emptying rate measurement in man. A double isotope scanning technique for simultaneous study of liquid and solid components of a meal. *Gastroenterology* 1976; 71:45–50.
21. Fisher R, Cohen S. Physiological characteristics of the human pyloric sphincter. *Gastroenterology* 1973; 64:67–75.