REFERENCES

1. Imahori Y, Fujii R, Ueda S, et al. No-carrier-added carbon-11-labeled *sn*-1,2- and *sn*-1,3-diacylglycerols by [^{11}C]propyl ketene method. *J Nucl Med* 1991;32:1622–1626.
2. Imahori Y, Fujii R, Ido T, Hirakawa K, Nakahashi H. Positron-labeled phorbol ester: synthesis method for "non-carrier added" phorbol 13-[1-^{11}C] butyrate using ketene reaction. *J Lab Compnd Radiopharm* 1989;27:1025–1034.
3. Fujii R, Imahori Y, Ido T, et al. New synthesis system of (C-11)propyl ketene and its reactions with various alcohols. *J Lab Compnd Radiopharm* 1991;29:497–505.

Yoshio Imahori
Ryou Fujii
Satoshi Ueda
Kyoto Prefectural University of Medicine, Nishijin Hospital
Kyoto, Japan

Proper Definitions for Lag Phase in Gastric Emptying of Solid Foods

TO THE EDITOR: Considerable controversy and confusion exists over the proper definition of the "lag phase" associated with the gastric emptying of solid foods. We are concerned that the conclusions reported in the recent publication by Christian et al. (*1*) may only add to this confusion.

The authors reported "a short solid meal lag phase (average 8.6 min) exists that can be missed with conventional radionuclide gastric emptying methods not employing continuous measurements." While we find no fault with the authors' experimental results, we believe that their finding of such a short lag phase is the result of failure to use an adequate solid radiolabeled meal. Most importantly, their conclusion that continous measurements are needed to perform a gastric emptying study is incorrect and, if accepted, would needlessly increase the complexity of this study.

Cannon first observed that the fundus and antrum play separate roles in emptying liquids and solids (*2*). He proposed that the fundus acts as a reservoir which initially undergoes receptive relaxation to receive food from the esophagus (*3*). Solids are then moved from the fundus to the antrum. Once in the antrum large particulate solids are ground by antral contractions into smaller particles by a process termed trituration. As stated correctly by Christian et al., solid particles do not empty through the pylorus until they are reduced to particles 1–2 mm in size (*4,5*).

We believe any definition of the lag phase must reflect the known physiology of gastric emptying of solids. We have previously shown that a lag phase based upon a definition that includes time for receptive relaxation and trituration is a function of ingested particle size and meal composition (*6,7*). Such a measure of the lag phase using the modified power exponential function has been studied using geometric mean attenuation correction and correlates with peak antral filling (*7*). This suggests that once solids fill the atrum and have been adequately triturated they begin to empty.

In their article, Christian et al. fail to ascribe any physiologic significance to their very short lag phase. We believe the very short lag phase reported by Christian et al. is merely a result of the fact that they have not used a sufficiently solid labeled test meal. They have labeled a liver pate, which as they state in their Material and Methods section, consists of particles 2–5 mm in size. Most of these particles therefore do not need to undergo trituration. Their short lag phase likely represents only the time for these small particles to reach the antrum following which they quickly begin to empty. The true solid in their study was the beef stew which was not labeled and therefore not evaluated.

In an earlier article, these authors validated their surface-labeled pate by comparison to an intracellular label and found similar emptying curves. It should be noted however that they diced the intracellularly-labeled chicken liver cubes into "2–3 mm chunks" (*8*).

As pointed out by Christian et al., numerous recent papers have reported that a lag phase for solid food emptying does exist. All these reports have used either whole in vivo chicken liver or labeled egg and not a liver pate (*7–14*).

Both articles they cited, which have supported the concept of no lag phase, used a radiolabel that did not label the solid [e.g., technetium-sulfur colloid mixed with mashed potato (*15*) and chromium-51 in porridge (*16*)]. In those articles, in which a true radiolabeled solid was employed, the graphs presented all show clear evidence of a lag phase (*5,17*).

The best definition of the lag phase remains controversial. Some have chosen to define the lag phase visually as "the part of the solid-emptying curve prior to the appearance of detectable amounts of radiolabel of the solid phase in the proximal small intestine" (*9*). While there is currently no consensus on the best method to measure the lag phase, it does appear to have clinical significance. It is a sensitive indicator of drug interventions employed to treat diabetic gastroparesis (*18*). Analysis of the lag phase has also been used to study the effects of ulcer surgery on gastric emptying. Mayer found obliteration of the lag phase following truncal vagotomy and pyloroplasty without an effect on trituration (*13*).

We believe the lag phase is best defined using a mathematical definition based on a model such as the modified power exponential curve fit (*6,7*). This obviates the need for continuous image acquisition using dual detectors which is not practical. Before committing others to such an approach, Christian et al. need to justify their conclusions by proposing a physiologic explanation for their very short lag phase.

REFERENCES

1. Christian PE, Datz FL, Moore JG. Confirmation of short solid-food lag phase by continuous monitoring of gastric emptying. *J Nucl Med* 1991;32:1349–1352.
2. Cannon WB. The movements of the stomach studied by means of the Roentgen rays. *Am J Physiol* 1898;1:359–382.
3. Cannon WB. The receptive relaxation of the stomach. *Am J Physiol* 1911;29:267–273.
4. Meyer JH, Ohashi H, Jehn D, Thompson JB. Size of liver particles emptied from the human stomach. *Gastroenterology* 1981;80:1489–1496.
5. Minami H, McCallum RW. The physiology and pathophysiology of gastric emptying in humans. *Gastroenterology* 1984;86:1592–1610.
6. Siegel JA, Urbain JL, Adler LP, et al. Biphasic nature of gastric emptying. *Gut* 1988;29:85–89.
7. Urbain JL, Siegel JA, Charkes ND, Maurer AH, Malmud LS, Fisher RS. The two-component stomach: effects of meal particle size on fundal and antral emptying. *Eur J Nucl Med* 1989;15:254–259.
8. 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.
9. 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;245:G580–G585.
10. 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.
11. Collins PJ, Horowitz M, Shearman DJC, Chatterton BE. Correction for tissue attenuation in radionuclide gastric emptying studies: a comparison of a lateral image method and a geometric mean method. *Br J Radiol* 1984;57:689–695.
12. Collins PJ, Horowitz M, Chatterton BE. Proximal, distal and total stomach emptying of a digestible solid meal in normal subjects. *Br J Radiol* 1988;61:12–18.
13. Mayer EA, Thomson JB, Jehn D, et al. Gastric emptying and sieving of solid food and pancreatic and biliary secretions after solid meals in patients with nonresective ulcer surgery. *Gastroenterology* 1984;87:1264–71.
14. Loo FD, Palmer DW, Soergel KH, Kalbfleisch JH, Wood CM. Gastric emptying in patients with diabetes mellitus. *Gastroenterology* 1984;485–494.
15. Scarpello JHB, Barber DC, Hague RV, Cullen DR, Sladen GE. Gastric emptying of solid meals in diabetics. *Br Med J* 1976;2:671–673.
16. Griffith GH, Owen GM, Kirkman S. Measurement of rate of gastric emptying using chromium-51. *Lancet* 1966;1:1244–1245.
17. Malmud LS, Fisher RS, Knight LC, Rock E. Scintigraphic evaluation of gastric emptying. *Semin Nucl Med* 1982;XII:116–125.
18. Horowitz M, Harding PE, Chatterton BE, Collins PJ, Sherman DJC. Acute and chronic effects of domperidone on gastric emptying in diabetic autonomic neuropathy. *Dig Dis Sci* 1985;30:1–9.

Alan H. Maurer
Linda C. Knight
Benjamin Krevsky
Temple University Hospital
Philadelphia, Pennsylvania

REPLY: We appreciate the interest of Maurer, Knight and Krevsky in our work. We agree that there has been considerable confusion over the existence and definition of a lag phase for solid food. Because of this confusion, we performed our study using three different techniques for measuring lag phase (*1*).

We have validated our solid food marker, labeled pate, against surface-labeled and intracellularly-labeled chicken liver (*2*). Labeled liver pate, surface- and intracellularly-labeled chicken liver were incubated in hydrochloric acid and gastric juice for up to 4 hr. Particulate radiolabeling efficiency was measured by sieving was greater than 93% at 3 hr for both liver pate and intracellular-labeled chicken liver. Surface-labeled chicken did not perform as well. We then performed two gastric emptying studies in each of six normal subjects; one study with labeled liver pate and the other with intracellularly-labeled chicken liver. The observed solid half-emptying time for pate and intracellularly-labeled chicken liver was 102 min and 100 min, respectively. No statistical difference in solid emptying time or the slopes of the emptying curves was found.

Maurer et al. reference an article in which a longer lag phase was found than in our paper (*3*). However, the subjects in that study swallowed chunks of food without chewing. As we stated in our article, food must be ground into 1–2 mm particles before emptying through the pylorus can occur (*1,4*). Our study was done, as are most other studies, under normal physiologic conditions, which include chewing as part of the digestive process. Trying to compare the size of our particles that were chewed to particles that were swallowed whole is not possible. These differences in experimental design would be expected to affect lag phase.

Maurer et al. also do not take into account other differences in experimental design that affect measurement of gastric emptying. We have shown that meal size, weight, and caloric content all affect gastric emptying. Meals of 300, 900 and 1700 g resulted in solid half-emptying times of 77, 146, and 277 min, respectively (*5*). Caloric content is an even more important criterion (*6,7*). A 300-g meal with a total caloric content of 68 kcal emptied with a half-emptying time of 73 min while a similar-sized meal containing 633 kcal emptied with a half-time of 214 min (*8*). Therefore, comparisons of different lag phase times likely are dependent on these variables, as well. In the article referenced by Maurer et al., the meal size caloric content were both higher than ours (*3*). Lag phase will be affected by variations in the volume and character of food, caloric content, imaging techniques and corrections.

We did not advocate the routine use of continuous monitoring for gastric emptying studies in our article. We pointed out that continuous monitoring with opposed detectors is necessary to ensure that all information is be appreciated and the first appearance of food into the duodenum may be missed. If this information is important for a particular study, then frequent imaging must be performed.

Although the power exponential function has been proposed by Elashoff et al. in an editorial, their group did not apply this technique in a specific study involving volunteer subjects or patients (*9*). Siegel et al. (*10*) have used a modified power exponential function to characterize variations in rates of emptying by a bi-phasic measurement technique (T_{LAG}). However, this does not measure lag phase as the onset of emptying from the stomach. Instead, it is intended to measure a period of time for antrum filling and trituration. By definition, the onset of emptying and T_{LAG} are different and the first onset of emptying should be shorter than T_{LAG}. These differences in terminology account for some of the confusion surrounding lag phase. Perhaps terminology should be changed to discern the difference between lag phase as the onset of emptying and a term to identify the time of curve shape change in a bi-phasic mathematical model.

REFERENCES

1. Christian PE, Datz FL, Moore JG. Confirmation of short solid-food lag phase by continuous monitoring of gastric emptying. *J Nucl Med* 1991;32:1349–1352.
2. 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;24:364–366.
3. Urbain JC, Siegel JA, Charkes ND, Maurer AH, Malmud LS. The two-component stomach: effects of meal particle size on fundal and antral emptying. *Eur J Nucl Med* 1989;15:254–259.
4. Meyer JH, Ohashi H, Jenh DJ, Thomson JB. Size of liver particles emptied from the human stomach. *Gastroenterology* 1981;80:1489–1496.
5. 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.
6. Hunt JN, Stubbs DF. The volume and energy content of meals as deterinants of gastric emptying. *J Physiol* 1975;245:209–225.
7. Velchik MG, Reynolds JC, Alavi A. Effect of meal energy content on gastric emptying. *J Nucl Med* 1989;30:1106–1110.
8. Brophy CM, Moore JG, Christian PE, Egger MJ, Taylor AT. Variability of gastric emptying measurements in man employing standardized radiolabeled meals. *Dig Dis Sci* 1986;31:799–806.
9. Elashoff JD, Reedy TJ, Meyer JH. Analysis of gastric emptying data. *Gastroenterology* 1982;83:1306–1312.
10. Siegel JA, Urbain JL, Adler LP, et al. Bi-phasic nature of gastric emptying data. *Gut* 1988;29:85–89.

Paul E. Christian
Frederick L. Datz
John G. Moore
University of Utah Medical Center
Salt Lake City, Utah