Techniques and Errors in Scintigraphic Measurements of Gastric Emptying

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For the monitoring of gastric emptying, a gamma camera or scanner operating from one side of the patient is subject to variations of counting efficiency due to the changing depth of radioactivity. A double-headed scanner was used to investigate the effects of such changes. Tc-99m and In-113m were used as labels for the solid and liquid components of a meal. It was found that the depth of Tc-99m within the stomach decreased by a mean of 13 mm during the first half hour of emptying. Anterior detection alone underestimated emptying rates by an average of 26%. Depth changes also introduced errors into "early emptying" measurements made unilaterally. Such artifacts of measurement may compromise mathematical analyses of emptying patterns.

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The measurement of gastric emptying in man by means of scintigraphy after ingestion of a meal containing an unabsorbable radioactive marker was introduced in 1966 (*1*), and has since been continued by many workers (*2*). Recent developments have included the special study of the early period of emptying (*3,4*) and the simultaneous measurement of solid and liquid emptying, using two different markers (*4,5*). Both of these topics are important in considering some of the effects of gastric surgery. Little has been published concerning the accuracy of scintigraphic measurements of gastric emptying. Our purpose in this paper is to examine the problems arising from variations in the depth of activity during its passage through the stomach and small intestine, and from variations in patient thickness. These problems are greatest when unilateral scintigraphy is performed, as with a gamma camera.

METHODS

Most of the methods used have already been described (*4*), but relevant points are summarized here.

In vivo methods. The meal consisted of corn flakes, sugar, and milk, to which was added In-113m DTPA as a liquid-phase marker and small pieces of paper impregnated with Tc-99m colloid and coated, to mark the solid phase. Rapid scanning was performed with a double-headed scanner at 10, 30, 60, 90, and 120 min after ingestion. The outputs from the anterior and posterior detectors were recorded separately, each by means of two pulse-height analyzers set on the photopeaks of Tc-99m and In-113m. The whole area of the abdomen was included in the first scan and on some occasions in subsequent scans. During scanning the patients were supine; between scans they sat in a chair. Quantitation was by dot counting over the stomach area and the remainder of the abdomen; manual counting was used in the earlier studies, area selection and integration on a computer display later on. Corrections were applied for penetration of the higher-energy radiation through the detector housing, the contribution of scattered In-113m radiation to the Tc-99m photopeak, and the time delay between the detectors' passage over the stomach and over the center of the postgastric activity.

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The thickness in the stomach region of some of the subjects was measured in the supine position with calipers, and also by determining the transmission of an external gamma ray beam using one of the scanning detectors. The transmission measurements were extended to the whole abdomen for some patients.

Subjects. Over 70 subjects were considered in the study, of whom 22 were patients who had undergone gastric surgery for peptic ulcer, 20 were normal volunteers in whom gastric emptying studies were performed as part of an evaluation of a new drug, 18 were patients with duodenal ulcers, and five were diabetics with autonomic neuropathy. The remainder had various gastro-intestinal disorders. The clinical conditions of the subjects were such that a wide range of gastric emptying rates was to be expected.

Phantom studies. Scans of a bottle filled with 150 ml of Tc-99m or In-113m solution were carried out at different depths in a phantom of unit density material. The variation of total counts with depth was close to exponential, with an attenuation coefficient, μ, of 0.12 cm^{-1} for the 140-keV emission of Tc-99m and 0.09 cm^{-1} for the 390-keV radiation from In-113m. As predicted from theory, the geometric mean of the counts from opposed detectors was dependent only on the overall thickness of the phantom and independent of source depth.

The sum of opposed counts showed a minimum in the centre; at a depth of 7 cm (the mean effective depth of the stomach) the variation was 4% per cm for Tc-99m, and 2% per cm for In-113m.

Calculations. Given an exponential attenuation, relative depths of the activity may be deduced from the ratio, R, of the counting rates from front and back. If the total thickness is t and the distance of a source from the central plane of the body is d, the recorded response from one side is proportional to $\exp[-\mu(t/2 - d)]$ and from the other side to $\exp[-\mu(t/2 + d)]$. The ratio, R, therefore is $\exp 2\mu d$, so that $d = \ln R/2\mu$. We therefore calculated d from the anterior and posterior counts in the stomach area for each of the scans, to investigate variations with time during the emptying process.

Emptying of the liquid-phase marker (In-113) approximated closely to a mono-exponential function over the period of 10–120 min, and rate constants were calculated from a linear regression of log counts against time. The pattern of solid-phase (Tc-99m) emptying was more complex and more variable, but in the majority of cases it approximated more closely to a linear rather than an exponential function. The results of regression analysis are therefore expressed as the percentage of the meal emptied per minute. These calculations were performed on the anterior counts alone, on the sum of the anterior and posterior counts, and on their geometric mean.

Two methods were used to calculate the early emptying, that is, the fraction of the ingested marker that had left the stomach by the time of the first scan. One was the indirect method proposed by Colmer et al. (*3*), which relates the counts recorded in the stomach area on the first scan to those in a similar scan of a known activity and placed in a unit-density phantom of the same thickness as the patient. The second was the direct method we have already described (*4*) relating the stomach counts to the total observed in the first total-abdomen scan.

RESULTS

Depth of stomach activity. The values of d were normalized to zero for the first scan, so that a positive value on any subsequent scan represented an anterior movement of stomach activity. Calculated from the Tc-99m scans, an anterior movement greater than 5 mm occurred between the first and second scans in 59 cases. In four cases a corresponding posterior movement occurred, and in 16 cases any movement was less than 5 mm. The mean movement was 13 mm (s.e.m. 11 mm). Later scans exhibited a wider range of depths, with no significant further mean movement. The mean anterior movement of the In-113m liquid marker between the first and second scans was 7 mm (s.e.m. 11 mm).

Effect on measurements of emptying rate. The anterior movement of activity between the first and second scans leads to an increased detection efficiency by an anterior detector, on average by 17% for Tc-99m and 7% for In-113m. It is to be expected, therefore, that the shape of the emptying curve will be affected. The mean of all Tc-99m-labeled solid-phase emptying curves is shown in Fig. 1a and for In-113m-labeled liquid emptying in Fig. 1b. The curves are normalized to 100% at the time of the first scan, rather than extrapolated to zero time, to show more clearly the correlation with the movements described above. The results obtained from the anterior and posterior detector outputs are shown separately, together with the results derived from the geometric means of those outputs. Because of the depth-independence already referred to, the geometric mean is assumed to represent the accurate measurement. It is evident that the use of the anterior (or posterior) detector alone gives a distorted picture. In particular, there often appears to be more activity in the stomach at the time of the second scan than at the first.

The effect on the measurement of emptying rate is shown for Tc-99m in Fig. 2a. Rates calculated from the anterior detector alone, (A), assuming a

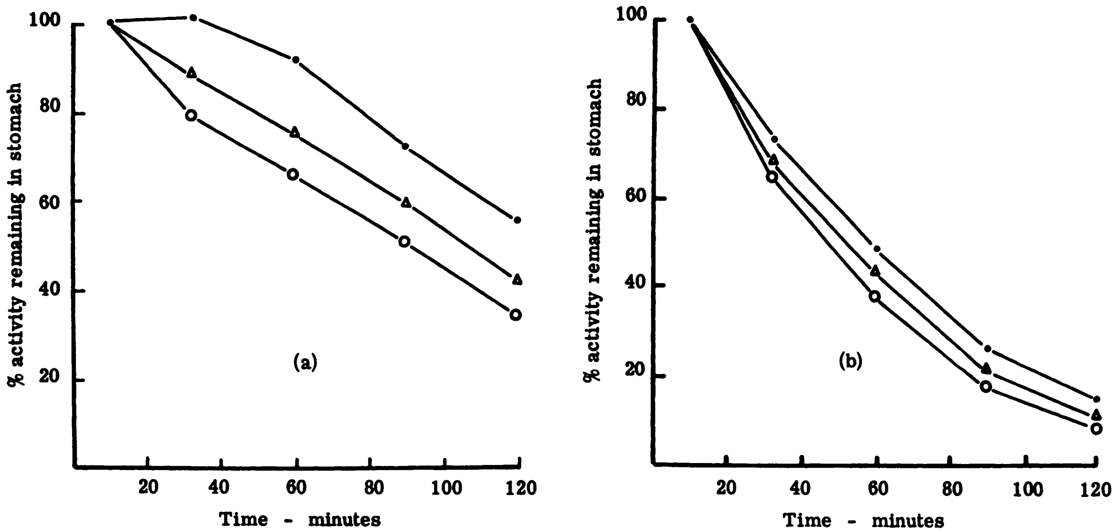

FIG. 1. Mean gastric emptying curves, (a) for a Tc-99m-labeled solid-phase marker (67 patients), and (b) for an In-113m-labeled liquid-phase marker (62 patients). Closed circles are used for anterior detector, open circles for posterior detector, triangles for geometric mean of both detector outputs.

linear relationship, are plotted against those from the geometric mean, (G), and the regression calculated. The regression equation was $A = 1.077\ G - 0.159$, $r = 0.891$. Although the correlation was good, the regression line departed from the line of identity to a highly significant extent. The average underestimate of emptying rate by use of the anterior detector alone was 26%, but there was considerable scatter in the results. In seven cases of slow emptying, the anterior detector alone yielded an increase of stomach activity with time over the 2-hr period!

In Fig. 2b rates determined for the Tc-99m tracer from the sum of the detector outputs (S), are compared with those from the geometric means. The agreement is now much better, the regression equation being $S = 1.002\ G - 0.037$, $r = 0.981$.

A similar pattern was found if the emptying rates were calculated from an exponential function. On average the anterior detector alone underestimated the emptying rate by 18%.

Similar comparisons were made for the In-113m liquid-phase marker, assuming an exponential emp-

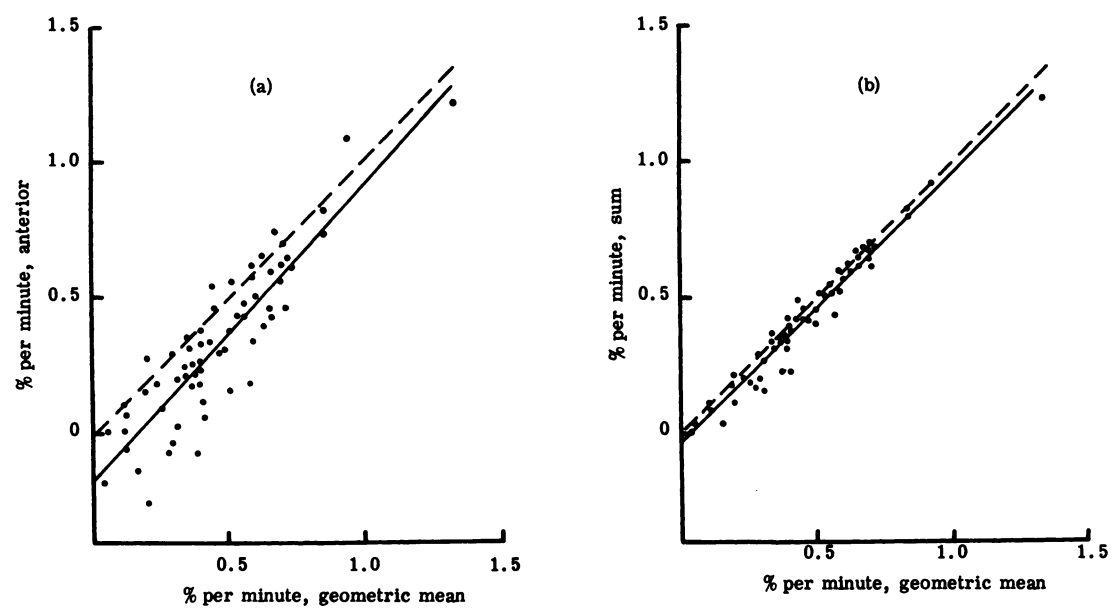

FIG. 2. Comparisons between determinations of percent of meal emptied per minute for Tc-99m-labeled solid-phase marker, (a) anterior detector compared with geometric mean, (b) sum of outputs compared with geometric mean. Broken line is line of identity, full line shows calculated regression.

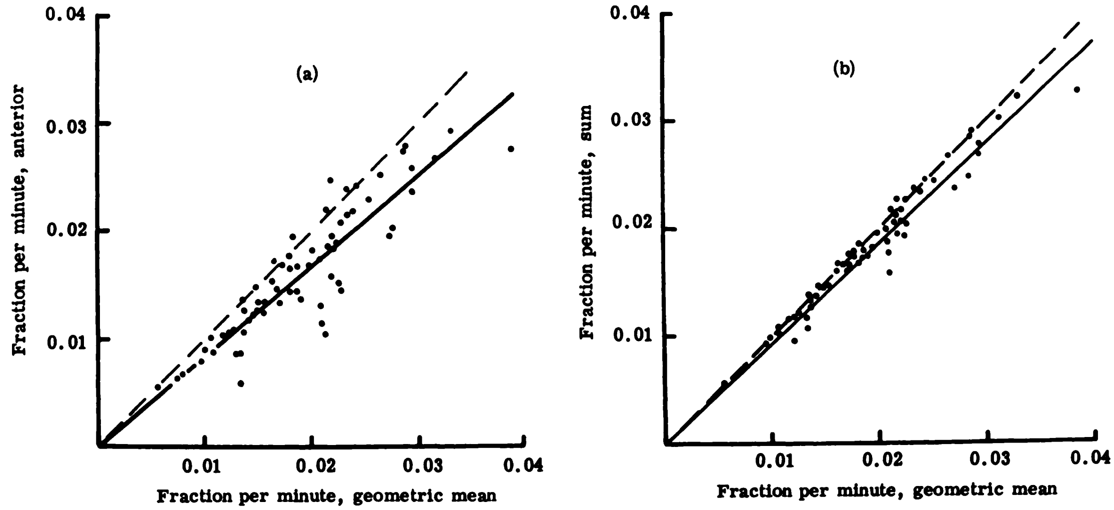

FIG. 3. Comparisons between emptying-rate determinations for In-113m-labeled liquid-phase marker, (a) anterior detector compared with geometric mean, (b) sum of outputs compared with geometric mean. Broken line is line of identity, full line shows calculated regression.

tying pattern. Rates from anterior and geometric mean results are compared in Fig. 3a. The regression line, A = 0.838 G + 0.000, r = 0.906, differed highly significantly from the line of identity. Although the average underestimate of emptying rate was 16%, in a few individual cases the anterior detector gave results in error by a factor of 2. The sum and geometric mean results are compared in Fig. 3b. The regression equation was S = 0.924 G + 0.000, r = 0.981.

If a posterior detector is used alone, on average the emptying rates are overestimated.

Early-emptying measurements. Owing to technical problems, the direct method of assessing early emptying from whole-abdomen scans was applied with separate recording from both detectors only for In-113m in 18 cases. On average the postgastric activity (B) at the time of the first scan was 3 cm more anterior than activity in the stomach (C) with little variation. *B* was thus over-estimated relatively by 30% if the anterior detector was used alone. The error introduced into the measurement of early emptying (E), however, was less than this, since E = B/(B + C). The regression line calculated from the plot of early emptying, measured as %, with the anterior detector only (E_A), against that using the geometric mean of anterior and posterior detector outputs (E_G) was $E_A = 1.035\ E_G + 3.43$, $r = 0.958$. The average disparity between E_A and E_G was 4% of the ingested activity, or 18% of the mean value of 22% for E_G. The maximum disparity was 10% of the ingested activity. When the sum of opposed detector responses (E_S) was used, the regression was $E_S = 1.002\ E_G + 1.56$, $r = 0.996$. Although the use of two detectors minimized the errors of early-emptying determinations, it is unlikely that unilateral detection would lead to the drawing of false conclusions. For Tc-99m occupying the same relative positions, *B* would be overestimated by 50% by an anterior detector. On average there was little change of the effective depth of the postgastric activity after the second scan.

Measurements of effective thickness. Caliper and transmission measurements of the effective thickness at the stomach position are compared in Fig. 4. There is a tendency for the geometric measurement to overestimate the effective thickness. Detailed transmission scanning showed that this was because lung tissue sometimes overlies part of the stomach. The accuracy of the Colmer et al. (*3*) method for measuring early emptying depends on the effective thickness of the subject and phantom being the same, or at least in a known relationship. The error in the assessment of stomach activity introduced by the mean disparity of 1 cm in our measurements is 6% for Tc-99m and 4.5% for In-113m. The maximum disparity of 2.5 cm gives errors of 17% and 12%. Since the amounts emptied are derived from the difference between activity administered and that determined in the first scan, the resulting inaccuracies can be significant.

Our own direct method of measuring early emptying relies on uniformity of the effective body thickness over all parts of the abdomen containing radioactivity, or on corrections made for variations. Complete transmission scans were carried out in 14 cases and effective thicknesses were determined over the stomach area and over the main concentration of postgastric activity at the time of the first scan. On average the former was greater by 2.4 cm (s.e.m. 1.7

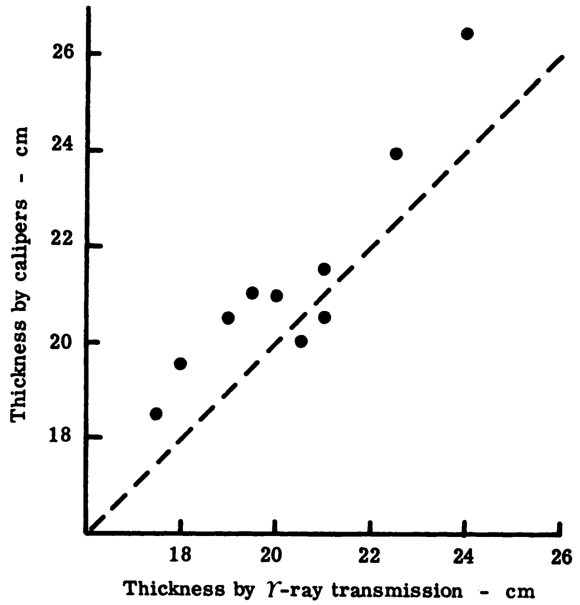

FIG. 4. Comparison between two methods of measuring body thickness over the stomach. Broken line is line of identity.

cm). If this thickness difference is ignored, the effect on the assessment of early emptying would be a mean overestimate of 11% of the value (s.e.m. 1.5%) for Tc-99m, and only 3% (s.e.m. 1.7%) for In-113m. In no case did the error exceed 25% of the early emptying value (only 5% of the administered dose). Our transmission-scanning technique enables us to eliminate the error, but at the expense of an increase in the complexity of the investigation. Fortunately, thickness differences can be ignored in this instance without much loss of accuracy.

DISCUSSION

Gastric emptying measurements using radioactive markers in normal meals have proved very useful in studying normal gastric physiology and the effects of disease, surgery, and drugs (*3,4,6–14*). Their value may be diminished by inaccuracies in the measurement technique, but little attention has been given to the nature and magnitude of possible sources of error. It was concluded from phantom measurements that depth variations would introduce little error (*15*), but a realistic model cannot have been used, since our measurements have shown that variations in the depth of activity usually introduce some inaccuracy when unilateral detection is used. Errors in measurements of emptying rate averaged 26% for Tc-99m-labeled solid phase and 18% for In-113m-labeled liquid phase, but were much greater in individual cases. Whether such errors are important will depend on the study for which the method is being used, but it seems likely that they will sometimes place a constraint on the interpretation of results.

The observation of an apparent plateau or rise in stomach activity as indicated by an anterior detector is not new, and indeed may reflect a real phenomenon, namely a delay in the commencement of gastric emptying. Alternatively such effects have been ascribed to activity in the duodenum or jejunum overlapping the area of interest in the stomach (*16*). Such overlap can certainly occur, but inspection of successive scans usually makes the possibility obvious and has led to its exclusion in our studies. More important, an overlap artifact would contribute also to the gastric emptying curve registered by the posterior detector. The considerable differences between the mean anterior and posterior curves in Fig. 1 demonstrate that overlap cannot be a significant factor in explaining the findings, especially as the duodenum is posterior to the stomach and our measurements of depth variation demonstrate a forward movement of activity during the first half hour of gastric emptying. This depth variation is not surprising. The body of the stomach is more posterior than the pylorus, so that any contents have to move forward before emptying.

The shape of the gastric emptying curve is undoubtedly of significance. At the simplest level, an increase of the slope during the first 10 min or so compared with that observed later on ("rapid early emptying") occurs after vagotomy or gastric resection. After 10 min, the emptying of a liquid marker closely follows an exponential curve. The pattern for our solid marker is more complex. Although we have found that it is usually approximated more closely by a linear than a logarithmic fit, it is clear that the approximation is rather crude. It might be expected that more information about the shape of the curve could be derived from the continuous recording available with gamma camera measurements. All such measurements have been from only one side of the body, however, and the variations of depth of activity that we have demonstrated superimpose artifacts on the real pattern of emptying of the stomach contents. Barber et al. (*10,17*) have applied principal-component analysis to the examination of gastric emptying curves derived from gamma-camera measurements. The interpretation of such analyses must be made with caution, since some of the features of those curves arise from the artifacts described.

The effect of depth variations can be minimized by the use of a higher-energy gamma emitter such as In-113m, but this results in a considerable loss of sensitivity when a gamma camera is used. Thus it would seem that, in the absence of a method of depth determination, bilateral detection is necessary for accurate studies of gastric emptying, and for many purposes a double-headed scanner is preferable to a gamma camera despite the superior temporal resolution of the latter. Although separate recording from two detectors, with calculation based on the geometric mean of their outputs, provides the best independence from activity depth variations, the summation of responses gives an acceptable alternative and simplifies the apparatus and data processing.

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REFERENCES

1. GRIFFITH GH, OWEN GM, KIRKMAN S, et al: Measurement of rate of gastric emptying using chromium-51. *Lancet* 1: 1244–1245, 1966

2. SHEINER HJ: Progress Report. Gastric emptying tests in man. *Gut* 16: 235–247, 1975

3. COLMER MR, OWEN GM, SHIELDS R: Pattern of gastric emptying after vagotomy and pyloroplasty. *Br Med J* 2: 448–450, 1973

4. 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* 71: 45–50, 1976

5. MEYER JH, MACGREGOR IL, GUELLER R, et al: ^{99m}Tc-tagged chicken liver as a market of solid food in the human stomach. *Am J Dig Dis* 21: 296–304, 1976

6. GRIFFITH GH, OWEN GM, CAMPBELL H, et al: Gastric emptying in health and in gastroduodenal disease. *Gastroenterology* 54: 1–7, 1968

7. DAVIES WT, GRIFFITH GH, OWEN GM, et al: The effect of vagotomy and drainage operations on the rate of gastric emptying in duodenal ulcer patients. *Br J Surg* 61: 509–515, 1974

8. HANCOCK BD, BOWEN-JONES E, DIXON R, et al: The effect of posture on the gastric emptying of solid meals in normal subjects and patients after vagotomy. *Br J Surg* 61: 945–949, 1974

9. MACGREGOR IL, MARTIN P, MEYER JH: Gastric emptying of solid food in normal man and after subtotal gastrectomy and truncal vagotomy with pyloroplasty. *Gastroenterology* 72: 206–211, 1977

10. HOWLETT PJ, SHEINER HJ, BARBER DC, et al: Gastric emptying in control subjects and patients with duodenal ulcer before and after vagotomy. *Gut* 17: 542–550, 1976

11. SCARPELLO JHB, BARBER DC, HAGUE RV, et al: Gastric emptying of solid meals in diabetics. *Br Med J* 2: 671–673, 1976

12. HAMLYN AN, MCKENNA K, DOUGLAS AP: Gastric emptying in coeliac disease. *Br Med J* 1: 1257–1258, 1977

13. HANCOCK BD, BOWEN-JONES E, DIXON R, et al: The effect of metoclopramide on gastric emptying of solid meals. *Gut* 15: 462–467, 1974

14. NIMMO WS, HEADING RC, WILSON J, et al: Inhibition of gastric emptying and drug absorption by narcotic analgesics. *Br J Clin Pharmac* 2: 509–513, 1975

15. HARVEY RF, MACKIE DB, BROWN NJG, et al: Measurement of gastric emptying time with a gamma camera. *Lancet* 1: 16–18, 1970

16. CHAUDHURI TK: Use of ^{99m}Tc-DTPA for measuring gastric emptying time. *J Nucl Med* 15: 391–395, 1974

17. BARBER DC, DUTHIE HL, HOWLETT PJ, et al: Principal components: A new approach to the analysis of gastric emptying. *Dynamic Studies with Radioisotopes in Medicine 1974*, IAEA Vienna 1975, pp 185–196