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A radionuclide study of regional gastric motility

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Summary

The aims of this research were to study some methodological aspects of radionuclide methods for assessing regional gastric motility and to determine the parameters that can be extracted along with their normal values or patterns. During the lag phase, the antral contraction curve showed three different patterns. At the beginning, the antral activity was too low to be analysed. Irregular variation of the count rate was then observed, followed by a more regular contraction. The application of Fourier transformation to the well-defined cyclical count rate variations revealed two areas with high amplitude values but with phase opposition. No peristaltic wave could be identified. After the lag phase, the antral curve showed cyclical variations of count rates with a frequency of about three cycles per minute. Slightly displaced curves but with a much lower amplitude were observed at different parts of the stomach. Several factors were found to influence the antral contraction curve, including the choice of region of interest and time since the last meal. Irregularities in the antral curve, both in terms of frequency and of amplitude, were not unusual in healthy subjects. These should be taken into account when interpreting antral contraction curves. The phase image showed a well-defined peristaltic contraction pattern. Three 360° cycles were usually observed throughout the stomach, suggesting that the time necessary for a peristaltic wave to sweep through from the upper part of the stomach to the antrum is about 1 min. Similar phase images were obtained in all subjects regardless of the amount of time since the meal containing the radioactive tracer, suggesting that gastric peristalsis can easily be assessed and interpreted. The amplitude image showed high amplitude in the antral area and in the greater curvature of the stomach. In the lesser curvature, the amplitude was much lower. Unlike the phase image, however, there was marked variability in the regional amplitude distribution. The value of the regional amplitude distribution for evaluating regional gastric motility is therefore limited.

Introduction

Although gastric motility is recognized as one of the most important gastric functions [1, 2], direct assessment of gastric contractility is rarely performed in clinical practice. This is because the methods available for this purpose, such as myoelectric techniques or regional intra-gastric pressure measurements, are somewhat invasive and difficult to perform routinely [1–4].

Information concerning gastric motility is often deduced indirectly from gastric emptying data. This approach, however, allows only a rough appreciation of the motor function of the stomach, because gastric emptying is influenced by numerous factors other than gastric motility [1, 5, 6]. Non-invasive radionuclide methods are particularly suited for the evaluation of time-related cyclical phenomena [7, 8]. However, applying these methods for the direct assessment of gastric contractility involves some technical difficulties. As no external signal of gastric peristalsis is readily available, gastric contractions should be identified by computer software. Data acquisition should therefore be performed either in high-speed frame mode or in list mode. The application of such a technique in routine clinical practice requires a computer with a large memory and high speed.

Due to developments in computer technology, high-performance computers are now incorporated in standard nuclear medicine equipment. Some studies have been reported in the literature concerning the radio-

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nuclide evaluation of antral contractility and gastric peristalsis [9–12].

The aims of this research were to study some methodological aspects of the radionuclide methods for assessing regional gastric motility and to determine the parameters that can be extracted along with their normal values or patterns.

Materials and methods

Subjects

Thirty healthy volunteers (17 males, 13 females), mostly members of the medical and paramedical staff at our institution, were recruited for this study. They were aged 21–64 years. They were all in good health and had no known medical problems. None of the subjects was on any form of medication.

Data acquisition

After refraining from eating for at least 6 h, the subjects were given one scrambled egg labelled with 37 MBq (1 mCi) $^{99}Tc^{m}$-sulphur colloid, two slices of white bread and 150 ml of water. Each subject ate the meal at their own pace and was then placed supine under a standard gamma camera equipped with a very sensitive collimator (Elscint Apex 405 and APC 1 collimator).

Data acquisition was started by performing two 1-min static images of stomach activity using the anterior and posterior projections, respectively. These were followed by a series of six successive 10-min data acquisitions of the stomach activity, performed using the anterior projection, with a 1-s frame time and a 64 × 64 matrix. During these acquisitions, the subject was left on his or her own in the camera room, which was kept as quiet as possible.

The data acquisition came to an end after performing further 1-min anterior and posterior images of the stomach activity.

Data processing

The early and late static images were used to estimate gastric emptying. Geometric means of the anterior and posterior data were calculated and the residual activity in the stomach 60 min after the meal was used as a parameter.

For the analysis of antral contraction and regional gastric peristalsis, an iterative data-processing method was used. We started by delineating, on a count density image, a region of interest (ROI) in the antral area. The time–activity curve for this ROI was then smoothed to eliminate statistical noise, and a series of well-defined cycles was selected. The data contained in each cycle were regrouped into 16 images. Then, by taking the frame with maximal activity as the starting point of each cycle, the different cycles were added together. The final result was a set of 16 images representative of a gastric contraction cycle, to which a Fourier transformation was applied. First harmonic phase and amplitude images were obtained.

The second step of the data processing began by redrawing a new antral ROI, which was delineated by taking into account not only the count density but also the regional phase and amplitude distribution. Care was taken to include only areas having similar phase values. The time–activity curve for this ROI was then generated and the above procedure was repeated: cycle selection, representative cycle formation and application of a Fourier transformation.

If the antral curve showed a regular contraction, the procedure was stopped. If the curve showed some irregularities, the procedure was repeated, beginning with the redrawing of a new antral ROI up to the application of a Fourier transformation on the representative cycle. An irregular antral contraction was only accepted if no further improvement could be obtained after executing the iteration six times.

The parameters evaluated were as follows: frequency and amplitude of antral contraction, regional distribution of contraction amplitude and regional propagation of gastric contraction or gastric peristalsis.

Results

General pattern of gastric motility after a solid meal

Figure 1 is an example of the results obtained at different times after the meal. During the first few minutes, the gastric contents were mainly located in the body of the stomach, with only a small amount of activity in the antral area. The activity then entered the antrum. Irregular variations in count rate were first observed in this area, followed a few minutes later by a more regular variation in count rate (Fig. 1B). Application of Fourier transformation to some of the regular variations in count rate revealed two well-defined areas with high amplitude values but with phase opposition (Figs 1C, 1D), probably reflecting the displacement of gastric contents inside the stomach. No peristaltic wave could be defined.

After the lag phase, the antral curve showed a better defined cyclical variation in count rate (Fig. 1F). Three cycles per minute was the usual frequency during the emptying phase. A slightly displaced curve but with a much lower amplitude was observed at different parts of the body of the stomach.

The phase image, obtained by applying Fourier transformation to these count rate variations, showed a well-defined peristaltic contraction pattern (Fig. 1G). Three 360° cycles were usually observed throughout the

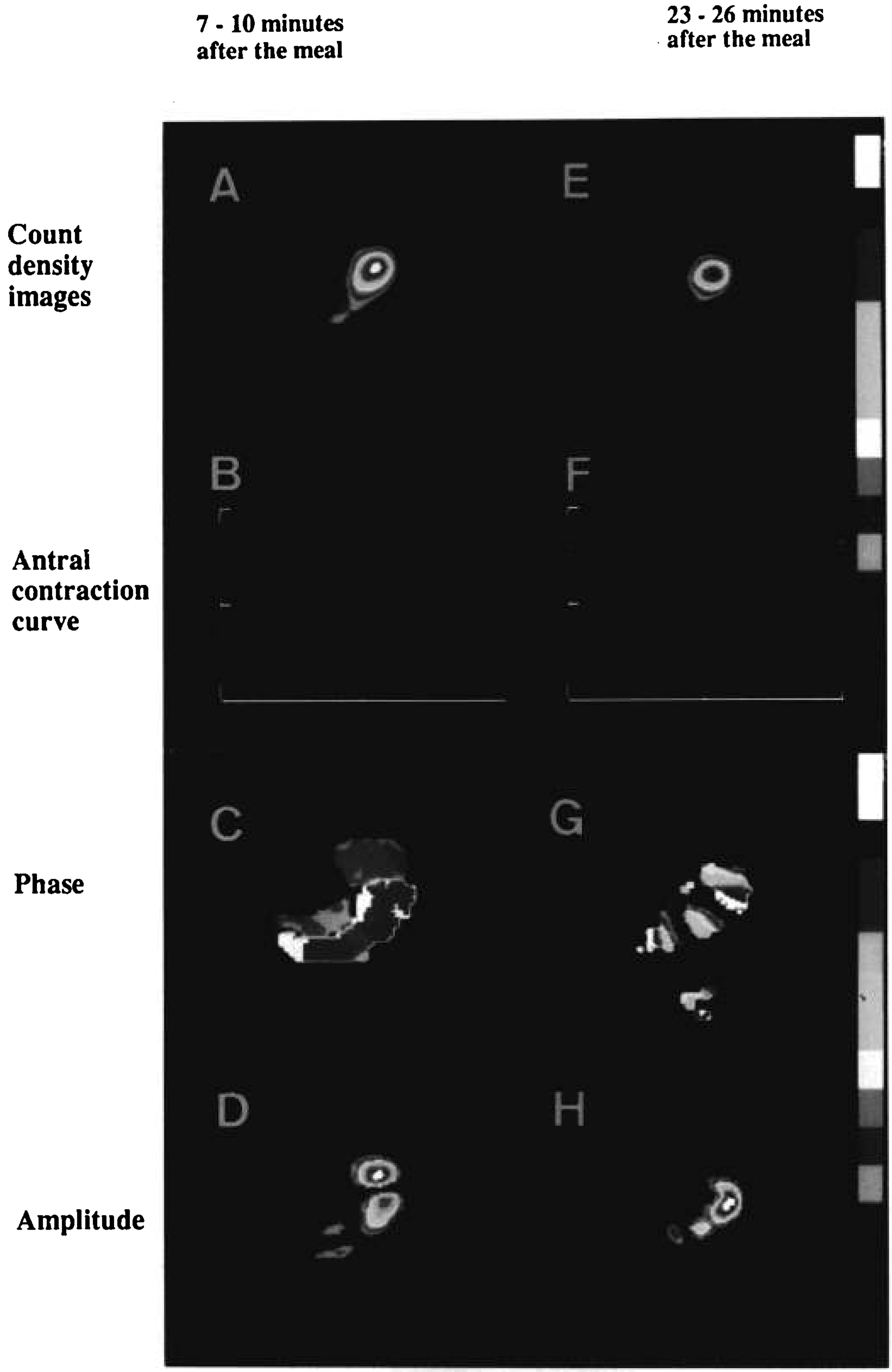

Fig. 1. Examples of results obtained at different times since the meal. During the first few minutes, the antral activity was too low to allow an assessment of antral contraction (A). In the body of the stomach, irregular variations in count rate were observed (B). The phase and amplitude images reveal two well-defined areas with high amplitude (D) values but with phase opposition (C). After the lag phase, the antral curve shows better defined cyclical variations in count rate with a frequency of about 3 cycles per minute (F). A similar, but slightly displaced curve was observed at different parts of the body of the stomach. The phase image (G) shows a well-defined peristaltic contraction pattern. Three 360° cycles are usually observed throughout the stomach. The amplitude image (H) shows high amplitude in the antral area and also in the greater curvature of the stomach; in the lesser curvature, the amplitude is much lower.

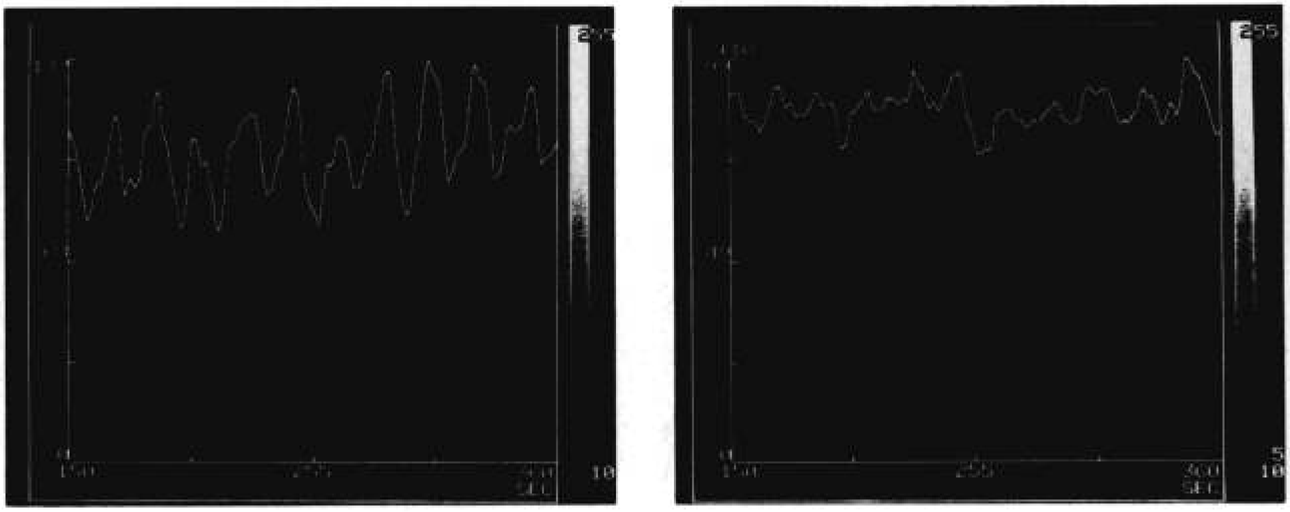

Fig. 2. An antral time–activity curve obtained for a small (left) and a large (right) antral ROI. A lower amplitude of antral contraction is observed for the large ROI.

stomach, suggesting that the time necessary for a peristaltic wave to sweep through from the upper part of the stomach to the antrum is about 1 min. When the radioactivity in the small bowel was large enough, peristaltic movement was shown to continue to the small bowel.

The amplitude image (Fig. 1H) shows that a high amplitude was observed in the antral area and in the greater curvature of the stomach; in the lesser curvature, the amplitude was much lower.

Antral contractility: Frequency and amplitude

Several factors influence the antral contraction curve, including choice of the ROI, time since the meal containing the radioactive tracer and individual variation. Figure 2 illustrates the effect of varying the antral ROI on the observed antral amplitude. Being peristaltic in nature, contraction in the different parts of the stomach does not occur simultaneously. Therefore, the shape and the amplitude of variations in the regional time–activity curve are highly dependent on the size and the location of the ROI. An artefactually lower amplitude could be observed for a large ROI.

Figure 3 presents two examples of antral curves recorded up to 60 min after the meal, and illustrates the fact that antral contraction, both in terms of frequency and of amplitude, is not always regular.

Subjective analysis of the post-lag phase antral curve indicated that regular antral contraction was only observed in 5 of the 30 healthy volunteers for more than 90% of the recording time. In 16 subjects it was predominantly regular, whereas in the remaining 9 subjects regular antral contraction was seen for less than 50% of the observation period. In this series, the quality of the antral curve was not related to gastric emptying rate, as the 60-min residual gastric activity was not significantly different among the three groups (mean ± S.D.: 46.8 ± 6.7, 43.4 ± 12.3 and 46.7 ± 12.4, respectively).

When only the well-defined antral contractions are taken into account, the intra-individual variability of antral frequency was low. For the 30 subjects studied, the mean coefficient of variation (S.D./mean) was 9% (range 6–15%). Inter-individual variability was also low, and was within the range of intra-individual variabilities. The mean antral frequency in the 30 subjects ranged from 2.9 to 3.2 cycles per minute. In this series, antral frequency was not related to the time since the meal. Between 20–30 min, 30–40 min, 40–50 min and 50–60 min after ingestion of the meal, the mean antral frequency was 3.10 ± 0.26, 3.20 ± 0.31, 3.00 ± 0.32 and 3.10 ± 0.32 cycles per minute, respectively.

Variability in the amplitude of antral contraction was more marked. The amplitude of antral contraction was usually low at the end of the lag phase, becoming more marked and often variable during the emptying phase (Fig. 3).

First harmonic phase image

As the count rate in each contraction cycle is rather low, similar cycles have to be added together to obtain a representative contraction curve to which Fourier transformation can be applied. When there are irregularities in antral contraction, the observer has to choose which cycles to add together. The subjective choice of the observer should therefore be taken into account when interpreting the results. On the first harmonic phase

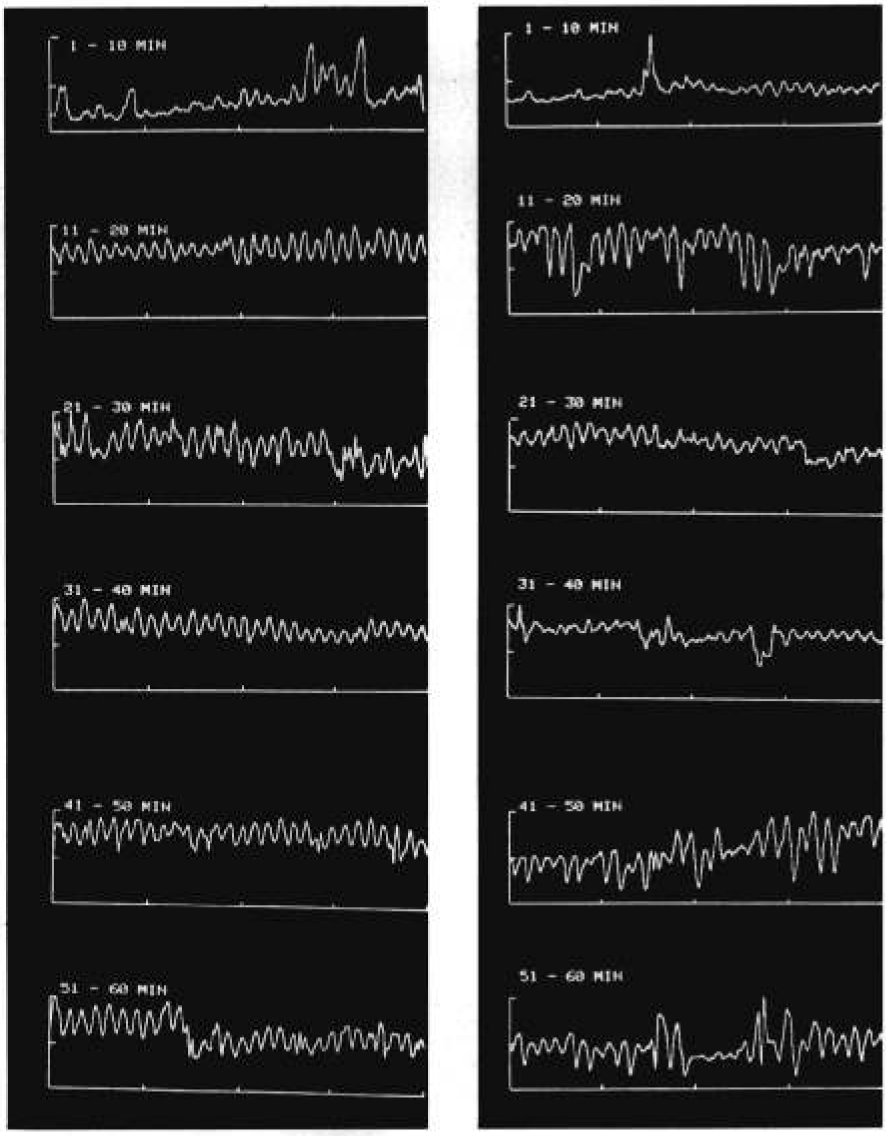

Fig. 3. An antral curve for a 60-min recording obtained in two healthy subjects. Early after the meal, the antral activity was low; it then increased gradually. The variation in cyclical count rate also became more regular with time. In the first example (left), the antral contraction was quite regular with only slight variations in contraction amplitude. In the second example (right), however, greater irregularity is observed, especially in contraction amplitude.

image, a regular peristaltic wave was depicted in all subjects. With the exception of the lag phase, similar phase images were obtained regardless of the amount of time since the meal (Fig. 4). There were no significant inter-individual differences. Furthermore, the choice of contraction cycles did not seem to influence the phase image. Between the upper part of the stomach body and the antral area, there were almost three systematic contraction waves. Only slight variations similar to that presented in Fig. 4 were observed.

First harmonic regional amplitude image

Unlike the phase image, the regional amplitude distribution showed marked variabilities related to the time since the meal (Fig. 4) and, more importantly, to the choice of the antral contraction cycles selected for Fourier analysis. Using the same 10-min data, the selection of contraction cycles could modify the amplitude distribution and produce amplitude variations similar to that presented in Fig. 4.

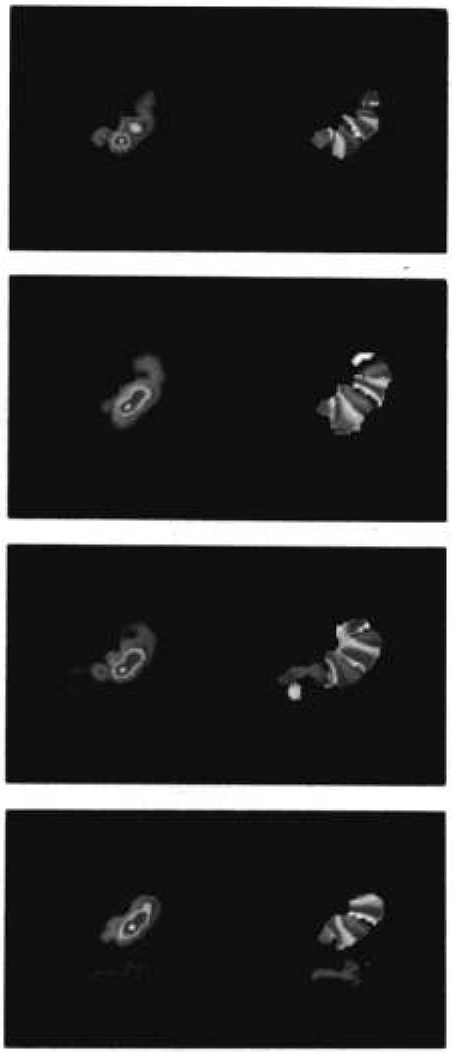

Fig. 4. Phase and amplitude images obtained at various times after the meal (from top to bottom: between 20–30 min, 30–40 min, 40–50 min and 50–60 min). While similar phase images (right) were obtained regardless of the time since the meal, marked differences in regional amplitude distribution (left) are observed.

Discussion

Direct assessment of gastric motility can be performed using myoelectric techniques or regional intragastric pressure measurements. These methods, however, are somewhat invasive and are difficult to perform routinely [1–4]. The use of gastric emptying to assess gastric motility is hampered by the fact that complex relationships exist between gastric contraction and gastric emptying, the latter being the result of the interaction of several mechanical, humoral and hormonal parameters [1, 2, 5, 6]. Gastric emptying, therefore, only provides an indirect and incomplete picture of gastric motility.

In agreement with a number of previous reports [9–12], we have shown that radionuclide methods can easily be implemented for the non-invasive assessment of regional gastric motility. However, some methodological difficulties do exist when obtaining and interpreting optimal parameters.

Different gastric contraction patterns are observed depending on the amount of time that has elapsed since the meal. During the lag phase, in the body of the stomach, the gastric contents seem to move up and down, probably reflecting the diluting, mixing and grinding process. Very little solid material leaves the stomach, probably because the solids have not been reduced to a particulate small enough to allow their passage through the pylorus [13]. No peristaltic wave is observed during this period.

After the lag phase, well-defined peristalsis and antral contractions are observed. The amplitude of the antral contraction curve is highly dependent on the size and the location of the ROI, as the contraction at the different parts of the antrum has different phases. An optimal antral ROI can therefore only be obtained by taking into account the phase and the amplitude images. An iterative procedure should be used to ensure that the antral curve obtained is not affected by errors in ROI delineation. Antral contractility is also dependent on the amount of time since the meal. Continuous acquisition over a long period of time is therefore necessary to allow for individual variations in lag phase.

Another problem when interpreting the antral curve is that antral contraction is not always regular. Despite the iterative data-processing method used, in more than 50% of our subjects, irregularities remained in the antral contraction curve. This was not necessarily related to an improper peristaltic wave. Indeed, despite the forceful antral contraction, food does not always pass to the duodenum. It may be just locally compressed or retropulsed for further mixing and emulsifying of the gastric contents.

For the above reasons, quantitation of antral contraction parameters is quite difficult. The dominant contraction frequency can be assessed using an autocorrelation function [12, 14]. This technique, however, does not give an indication of the frequency variabilities. The assessment of contraction amplitude is even more difficult because many factors – both technical and physiological – may influence the apparent irregularities in the antral curve. Fourier transformation or other standard time-series analysis [12, 14] can be used to isolate the frequency and the amplitude of various components of the time–activity curve, but in the presence of irregularities, physiological interpretation of the results is hazardous. For these reasons, great care should be exercised when comparing two irregular antral curves. Our personal preference is for subjective evaluation. Given two irregular antral curves, we can always determine subjectively which curve, as a whole, has a higher antral frequency and which one has a higher amplitude of antral contraction. Statistical analysis can then be performed using standard rank order tests. This approach has the advantage of not being subjected to eventual erroneous numerical results due to the inappropriate application of mathematical models.

Due to the low count rate, Fourier transformation cannot be applied to each cycle individually. Selection of a number of cycles should be performed either subjectively or by using some pre-established criteria. Whatever the method employed, it should be remembered that the resulting phase and amplitude images are representative only of the cycles selected.

This restriction is not important when interpreting the phase image because it appears to be unaffected by the time since the meal or by the choice of antral contraction cycles for Fourier transformation. However, it would seem to be relevant for the regional amplitude distribution. Modification of the amplitude distribution related to the time since the meal could be due to the proximal–distal displacement of the gastric contents. Such variability, which is rather smooth in time, should be taken into account when interpreting the amplitude image. Our study, however, also revealed that regional amplitude distribution varies for each antral contraction cycle. This observation may be explained by the fact that gastric contraction is relatively feeble and does not occlude the lumen completely [13]. Irregular movement of the gastric contents can therefore occur, especially in an irregular structure like the stomach. However, it constitutes an important limiting factor for the use of regional amplitude distribution in the evaluation of regional gastric motility. Only by adding together a large number of antral contraction cycles, can a representative amplitude image be obtained. Unfortunately, this is hampered by the fact that irregular antral contraction even occurs in healthy subjects.

Despite these limitations, our study suggests that radionuclide methods can be used to assess regional gastric motility. Due to the non-invasive nature of the technique, it could be useful in a wide range of clinical, physiological and pharmacological investigations. The methods can be performed in healthy subjects as well as in patients presenting with various disorders. Regional gastric motility can be recorded continuously over a few hours. Modifications to gastric contractility can easily be assessed, for example after a physiological or pharmacological stimulus.

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