# Visualization of the Gastric Mechanical Systole Using a New Scintigraphic Technique

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Using the standard radionuclide gastric emptying test combined with a new data acquisition and processing method, we have been able to visualize the contractions of the stomach and to generate the gastric mechanical systole. After ingestion of a radiolabeled test meal, list mode images of the stomach were acquired at different time intervals for 2 hr and processed to generate distal stomach time-activity curves. A curve-peak finding algorithm was applied to each time-activity curve to indicate the start of every gastric cycle. List mode images were re-framed in 20 images per cycle and 20 pseudo-gated images consisting of the sum of the same numbered frame interval in every cycle were generated for each dynamic acquisition set. Fourier analysis of the time-activity curve in each gastric pixel location of the 20 pseudo-gated images allowed for the generation of phase images of the stomach in a color scale. The closed-loop cinematic display of the phase images during a gastric cycle enables one to visualize the progression of the gastric contraction wave, that is, the gastric mechanical systole. Correlations between the antral time-activity curve cycles and gastric contractions were established in five dogs using simultaneous isotopic and serosal electrogastrographic recordings. The patterns of phase distribution and sequential phase changes of the food in the stomach that we have observed noninvasively indicate that the proximal stomach does not undergo phasic contractions, while in the distal stomach contractions originate in mid-corpus and propagate aborrally to the pylorus. The scintigraphic test can be used to noninvasively visualize gastric contractions and to delineate the spatial progression of the gastric electromechanical wave of contraction.

After eating, characterization of human gastric motility is difficult to achieve by internal recording because peristaltic waves are not always lumen-obliterating (1) and electrodes detach from the mucosa in response to mucus secretion and excess gastric wall motion (2). Contrast radiography (3-5) and real-time ultrasonography (6-7) have also been applied to visualize post-prandial antral contractions. However, these procedures have technical limitations and cannot be routinely employed to visualize the mechanical activity of the human

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stomach. The purpose of this study was to develop and validate a new scintigraphic acquisition and processing method to visualize and characterize gastric contractions in normal subjects.

## MATERIAL AND METHODS

Ten healthy male volunteers (mean age  $23 \pm 2$  yr) were studied. All denied consumption of drugs or alcohol and none had gastrointestinal complaints or a history of gastrointestinal surgery. The study was approved by the Ethical Committee of the Catholic University Hospital of Leuven in November 1988 and informed consent was obtained from each volunteer.

After an overnight fast of 12 hr, each volunteer ate a standardized meal consisting of 20 grams of a beaten raw egg labeled with 3 mCi of technetium-99m- (<sup>99m</sup>Tc) sulfur colloid and steam-cooked, 2 slices of white bread, 60 grams of low cream cheese, and 150 ml of water. The radiation burden associated with this study was 1.35 rads for the upper large intestine (the target organ) and 0.054 rads for the whole body (8).

Immediately after ingestion of the meal, each volunteer was placed between the two heads of a dual-headed gamma camera equipped with parallel-hole low-energy collimators and interfaced to a computer. Simultaneous anterior and posterior static  $128 \times 128$  matrix images were acquired using the 140keV <sup>99m</sup>Tc photopeak with 20% energy windows for 1 min every 10 min for 2 hr. All images were decay-corrected. Regions of interest (ROIs) were drawn around each image of the stomach and for each time interval geometric mean counts were generated as the square root of the product of anterior and posterior counts. Percentage of activity remaining in the stomach was determined. List mode images, 64 matrix with a 2.6 acquisition zoom, of the stomach were also acquired for 5 min at 15, 31, 61, 91, and 121 min after meal completion. Each set of list mode frames was compiled in a 5-min static image to draw a ROI around the antrum and subsequent 250 msec decay-corrected geometric mean frames were generated.

An edge-detection algorithm was then applied to each frame to precisely outline the antrum and antral time-activity curves were generated. With the amount of radioactivity within the antrum being directly proportional to the amount of food,

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changes in the antral time-activity curve parallel changes in antral volume and reflect antral contractions. The sinusoidal curves obtained were fitted using the first harmonic Fourier fit in order to determine the frequencies of antral contractions. A curve-peak finding algorithm was then applied to each time-activity curve to indicate the start of every gastric cycle. List mode images were then re-framed in 20 images per cycle, and for each 5-min set of dynamic acquisition 20 pseudogated images consisting of the sum of the same numbered frame interval in every cycle and a single composite timeactivity curve were generated. Repeatedly viewing the 20 frames of the pseudo-gated image in rapid sequence on the computer gave the dynamic motion of the gastric walls. The first harmonic Fourier analysis of the time-activity curve in each gastric pixel location of the 20 pseudo-gated images allowed for the determination of the pixels which had the same relative timing on the composite curve. Phase images were created by assembling those pixels with the same timing during the gastric cycle in a color scale. The closed-loop cinematic display of the phase images during a gastric cycle enables the visualization of the progression of the wave of gastric contraction, i.e., the gastric mechanical systole for that cycle.

Correlations between the antral time-activity curve cycle and gastric contractions were established in five dogs using the serosal electrogastrographic technique. Three weeks after surgical implantation of four bipolar silver chloride electrodes distributed from the terminal antrum to the proximal fundus, each dog underwent the isotopic procedure described above. Simultaneous isotopic and serosal electrogastrographic recordings were performed. Scintigraphic data were processed as previously mentioned to individualize the gastric cycles and electrogastrographic tracings were analyzed visually to determine the electrical spike activity.

The ratios between the number of isotopic cycles and of plateau potentials were calculated for each list mode acquisition period. Statistical analysis was performed using the Student's paired t-test and correlations were analyzed using the r coefficient.

#### RESULTS

Correlation between the dog antral time-activity curve and the simultaneous antral serosal electrogastrogram for a period of 1 min is shown in Figure 1. Each isotopic antral cycle was clearly individualized and corresponded to an electrographic signal which was characterized by a slow wave followed by an electrical response activity which determines a contraction. The mean frequency of contractions obtained using the first harmonic Fourier fit of the antral time-activity curves was five per minute. The ratio between the frequency of isotopic gastric cycles and the number of contractions was close to unity for each dynamic acquisition set in each dog (r = 0.97).

A 5-min time-activity curve is represented in Figure 2 for one volunteer. Fourier analysis resulted in excellent fits (mean chi-square  $35 \pm 10$ ) to determine the mean frequency of contractions (three per minute). Expressed as the mean num-



**FIG. 1.** Correlation between a dog's 1-min antral activity curve (bottom) and its electrogastrogram (top). Each antral activity cycle corresponds to an electrical response activity (closed arrow) which follows a slow wave potential (opened arrow). Five antral cycles or contractions are clearly individualized.

ber of antral cycles per minute for each 5-min set of images, antral contraction frequency significantly increased when gastric emptying proceeded (Fig. 3).

The 20 images in Figure 4 show the progression of the gastric walls movements from the caudad corpus to the terminal antrum. Images are sequenced from top to bottom and left to right. At the beginning (Images 1 and 2), the food in the distal stomach is compact and a slight depression of the gastric wall can be seen (white arrow) on the lesser curvature. This depression becomes more pronounced when progressing to the antrum (Images 3 to 6) and is accompanied by a similar movement of the greater curvature wall (Image 6). Both waves then simultaneously progress and generate a ring of contraction which closes the antrum (Images 8 to 17) and retropells most of its contents (Images 18 to 20).

The global phase image of the stomach (Fig. 5) allowed for the characterization of the relative motion of gastric contents in the different regions of the stomach in a color scale. A unique phase was seen in regard to the proximal stomach which does not undergo any phasic activity. In contrast, the two complete color shades observed in regard to the distal



**FIG. 2.** An antral time-activity curve is shown for a 5-min list mode acquisition in one volunteer. The curve is sinusoidal and can be analyzed by a first harmonic Fourier fit to determine the frequency of the antral cycles.



FIG. 3 Antral frequency is plotted with percentage of meal retention on a double Y-axis graph. Frequency of the antral contractions slightly, but significantly, increases when gastric emptying proceeds.

stomach clearly showed the phase progression of a contraction in the antrum and the following one in the corpus as it is often observed in healthy subjects. The color scale clearly demonstrated that the contraction in the corpus begins in a zone located along the greater curvature at the junction of the proximal and distal stomach which is the gastric pacemaker.

## DISCUSSION

Almost a century ago, Cannon used Röentgen rays to describe the motor activity of the cat stomach (3-4); more recently, Code characterized the motor action of the gastroduodenal junction in dogs by cineradiography (5). Real-time ultrasonography has also been applied to visualize antral contractions (6-7). These techniques, however, do not allow for the characterization of the post-cibal stomach electromechanical activity and, so far, most of the knowledge of the



FIG. 4 The progression of gastric wall movements from the caudad corpus to the terminal antrum is shown in 20 images sequenced from top to bottom and left to right.



**FIG. 5.** The color image of the stomach represents the different phases or levels of mechanical activity of the various portions of the stomach. In the proximal stomach, no phase change, i.e., no contraction is seen. In contrast, the distal stomach shows a complete phase progression that is a complete mechanical cycle in the antrum and another one in the corpus. The < indicates the origin of the contraction on the greater curvature.

gastric motor function after feeding has been inferred from invasive recordings during the fast pattern (9-15).

Using the standard radionuclide gastric emptying test combined with a new data acquisition and processing method, we have shown in this study, first, that it is possible to determine changes in antral food content and, second, that the isotopic antral cyclical changes paralleled the antral electrical response activity, that is, the antral contraction. The mean frequency of ~5 cycles per minute we have obtained for gastric contractions in the dog and the frequency of ~3 cycles per minute in healthy human male volunteers is in agreement with the literature data (1). The slight variation of the mean frequency of the antral contractions we have observed when gastric emptying proceeds could be explained by the greater excitability of antral phasic contractility by particulate food compared to homogenate foodstuff when digestion proceeds (16).

Visualization of cardiac contraction and phase analysis of blood-pool scintigrams are routinely performed in nuclear cardiology using the gating technique (17-18). The lack of a good noninvasive electrical signal to separate gastric cycles has impaired the application of the electrocardiographic signal to the stomach. We have, therefore, developed a curve-peak finding algorithm to indicate the start of each gastric cycle which was then divided into multiple intervals and frames. The main interest of the closed-loop cinematic display of those frames rests upon the evaluation of the whole gastric wall motion which cannot be obtained on a routine basis by any other technique, nor particularly, by contrast radiography due to the radiation exposure involved.

The normal human stomach consists of two anatomically integrated, but electromechanically distinct parts: the proximal stomach, which encompasses the fundus and the orad corpus and is mainly a tonic muscle without phasic contractions; and the distal stomach, which includes the mid- and caudad corpus and the antrum and undergoes contractions propagating away from the mid-corpus towards the gastroduodenal junction (19). The patterns of phase distribution and sequential phase changes of the food in the stomach we

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have observed demonstrated and confirmed noninvasively that the proximal stomach does not undergo phasic contractions and that, in the distal stomach, smooth muscle activation originates in the mid-corpus and propagates aborrally to the pylorus. This is in agreement with results already obtained by other investigators with invasive techniques (9-15).

In conclusion, the scintigraphic test can be used to noninvasively visualize gastric contractions and to delineate the spatial progression of the gastric electromechanical wave of contraction. This technique can be applied to studying the physiopathology of gastric emptying with various motor disorders.

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