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Postprandial Response of Gastric Slow Waves: Correlation of Serosal Recordings with the Electrogastrogram

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Controversial interpretations have been given to the postprandial increase in the dominant power (amplitude) of the electrogastrogram (EGG). The aim of this study was to find an appropriate interpretation of the postprandial EGG power changes. Simultaneous serosal and cutaneous recordings of gastric myoelectrical activity were made in 11 patients with gastroparesis in the fasting state and after the ingestion of 8 oz of water. The dominant frequency and corresponding power of the recording before and after water were computed using the power spectral analysis method. It was found that the dominant frequency of the EGG was the same as that of the serosal recording in 10 patients. One patient showed a substantial amount of dysrhythmia and no obvious dominant frequency was noted. A decrease in the dominant frequency was found in these 10 patients after the ingestion of water. Tachygastria of higher than 4 cycles/min was observed in one of 11 patients both in the prewater and postwater states. Consistent changes in amplitude after a drink of water were noted in both serosal recording and EGG. Statistical analysis demonstrated that the dominant power change after water computed from the EGG was correlated with that observed in the serosal recording ($r = 0.757$, $P = 0.007$). In conclusion, exogenous stimulation, such as ingestion of water, may change the amplitude of the gastric slow wave and this change is reflected in the EGG, suggesting that the change of the slow-wave amplitude is an important contributing factor to the postprandial change in the EGG dominant power.

KEY WORDS: gastric myoelectrical activity; electrogastrogram; gastroparesis; gastrointestinal motility; stomach.

As in the heart, there is myoelectrical activity in the stomach. Gastric myoelectrical activity consists of slow waves (or electric control activity) and spikes (or electric response activity) (1, 2). The slow wave originates in the upper part of the stomach and is present all the time, propagating circumferentially and distally toward the pylorus with increasing velocity and amplitude (2–4). It is known that the slow wave controls the frequency and propagation of the gastric contractions. Spikes are directly associated with gastric contractions. Gastric contractions occur when slow waves are followed by spikes. Gastric myoelectrical activity can be measured by cutaneous electrodes placed on the abdominal skin over the stomach. The cutaneous recording of gastric myoelectrical activity is usually called the electrogastrogram (EGG) (1). The use of the EGG is very attractive since the

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method is noninvasive and does not disturb on-going activity of the stomach.

What is measured in the EGG? Simultaneous recordings of cutaneous and serosal (5–8) or cutaneous and mucosal (9–11) myoelectrical signals have confirmed that the dominant frequency of the EGG is of gastric origin and is the same as that of gastric slow waves measured from internal electrodes. The most recent studies have indicated that the frequency of gastric slow waves in healthy human is in a range of 2.4 to 3.7 cpm (12–14). Abnormalities in this frequency (dysrhythmias) have been considered to be associated with gastric motility disorders (10, 15–20). On the other hand, the clinical and physiological significance of the amplitude of the EGG (or the power at the dominant frequency) is not yet clear. EGG amplitude changes have been frequently observed in the postprandial state (21–25). The interpretation of this change is controversial, however. While most of researchers believe that the postprandial increase of the EGG amplitude reflects increased contractility of the stomach (6, 21, 26), some investigators suggest that the increase of the EGG amplitude is due to physical distension that brings the stomach closer to the cutaneous electrodes (9, 24, 27, 28). Recently, however we have found that the amplitude of the gastric slow wave measured from the implanted serosal electrodes may change upon exogenous stimulation (29). This study was design to use simultaneous serosal and cutaneous recordings of gastric myoelectrical activity in patients with gastroparesis to test the hypothesis that the amplitude of gastric slow waves may change after eating and may contribute to the amplitude change of the postprandial EGG.

MATERIALS AND METHODS

Subject. Eleven patients (2 men and 9 women; mean age: 36.1 years; range: 19–52 years) with severe gastroparesis refractory to standard medical therapy were included in this study. All patients had documented delayed gastric emptying of an isotope-labeled solid meal before enrollment. Seven patients had diabetic gastroparesis, two were idiopathic, and two were postsurgical. All patients had been receiving a full regimen of standard medical therapy but still required an abdominal surgery (laparoscopic approach) for the placement of a feeding jejunostomy tube (J-tube). The study protocol was approved by the Human Investigation Committee at University of Virginia Health Science Center, and written consent forms were obtained from all subjects before the study.

Placement of Serosal and Cutaneous Electrodes. During the scheduled surgery for the placement of the feeding jejunostomy tube, four pairs of temporary 28-gauge electrodes (A & E Medical, Farmingdale, New Jersey) were implanted on the serosal surface of the stomach. They were arranged in an arching line along the greater curvature from the corpus to the pylorus. The distance between two electrodes in the pair was 1 cm, and the distance between two adjacent pairs of electrodes was 3–4 cm. The most distal pair of electrodes was 2 cm above the pylorus. The electrodes were affixed to the gastric serosa by partially embedding the wire in the seromuscular layer of the stomach. The electrode wires were brought out through the abdominal wall percutaneously and placed under a sterile dressing.

Prior to the placement of cutaneous electrodes, the abdominal surface where electrodes were to be positioned was shaved, if hairy, and cleaned with sandy skin-prep paste (Omni Prep, Weaver & Co., Aurora, Colorado) to reduce the impedance. Two silver–silver chloride ECG electrodes (DNM, Dayton, Ohio) were placed on the abdominal surface over the stomach. One electrode was positioned at the midpoint between the xiphoid process and the umbilicus. The second electrode was placed on the subject's left side, just below the lower rib and above the level of the first electrode. A reference electrode was placed in the lower quadrant close to the left costal margin.

Simultaneous Serosal and Cutaneous Recordings. All recordings were made in a quiet room, starting at least one week after surgery. On the day of the study the patient was fasted for at least 6 hr and given no medication with known effects on gastrointestinal motility. The patient was lying in a supine position during the study and was asked not to talk or move and to remain as still as possible during recording to avoid motion artifacts. Simultaneous EGG and serosal recordings were made for 20 min in the fasting state. Then the patient sat up and drank 8 oz of water at room temperature. After drinking the patient resumed the supine position the recording continued for another 20 min. The recording of gastric myoelectrical activity from the implanted serosal electrodes was made using a Hewlett Packard model 7758B Stripchart Recorder (Palo Alto, California). The signals were displayed on the chart and simultaneously recorded on a tape recorder. The low and high cutoff frequencies of the recording device were 0.02 and 30 Hz, respectively. The cutaneous EGG signal was simultaneously recorded using a portable EGG recorder (Synectics, Irving, Texas) with low and high cutoff frequencies of 1 and 18 cpm, respectively, and simultaneously digitized at a sampling frequency of 4 Hz and stored on the recorder.

Data Analysis. To investigate the postprandial power change of the EGG and its correlation with the change of gastric slow wave quantitatively, in each patient serosal and cutaneous signals simultaneously recorded 10 min before and during the first 10 min after drinking the water were selected and subjected to computerized spectral analysis. The EGG data stored on the recorder were downloaded to a 586 personal computer and sampled again at 2 Hz. Using a locally developed program, all data were first subjected to visual inspection to exclude those with severe motion. The serosal signals were played back from the tape recorder, digitized by a 12-bit analog-digital convertor (Data Instruments, Inc., Akron, Ohio), and stored in ASCII files on the same 586 personal computer. The sampling frequency was 60 Hz. To reduce the volume of data, the digitized serosal

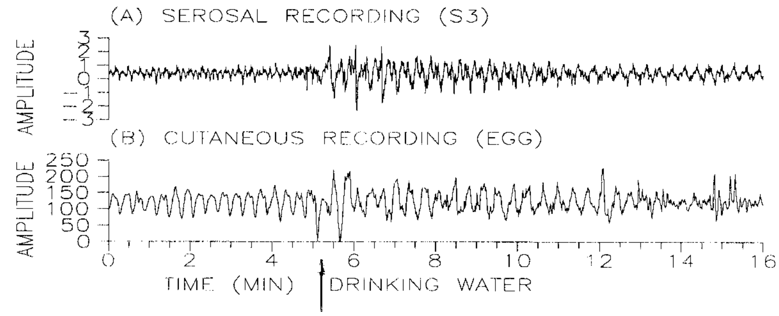

Fig 1. Examples of simultaneous serosal (A) and EGG (B) recordings before and after drinking water showing that there was a simultaneous amplitude increase in the EGG and serosal recordings after drinking water.

recording was filtered by a digital low-pass filter with a cutoff frequency of 0.5 Hz and sampled again at 2 Hz. A smoothed power spectral analysis, called the periodogram method (30), was applied to compute the power spectra of both EGG and serosal recordings. The dominant frequency and power of the EGG and serosal recordings were assessed from the power spectra. Decibel (dB) units were used to present the power of the signal (14). The relative change of the dominant power for the EGG and serosal signals were also calculated, which is defined as the power ratio after and before certain stimulation (eg, water). When decibel units are used, as is the case in this study, the relative change of dominant power is defined as the difference between dominant powers (in dB) after and before the stimulation.

The percentages of normal slow waves and the percentage of dysrhythmias were determined by visual inspection of raw signals and by using the adaptive running spectral analysis method (14). Rhythmic activity with a dominant frequency of 2–4 cpm was defined as the normal slow wave. The percentage of normal slow waves (or dysrhythmias) was defined as the percent of time during which normal slow waves were present (or absent) over the entire observation period. This definition is in accordance with several previous reports (15, 19, 25, 31–33). Gastric dysrhythmias include bradygastria, tachygastria, and arrhythmia (no rhythmic activity or mixed activity with different frequencies). Bradygastria was defined as activity between 0.5 and 2.0 cpm lasting for at least 2 min. Similarly, tachygastria was defined as the dominant frequency of slow waves between 4.0 and 9.0 cpm.

Statistical Analysis. Correlation between the amplitude changes of the EGG and the serosal signal was determined by calculation of Spearman's rank correlation coefficients (34). Differences between parameters before water and the corresponding parameters in the postwater state were assessed by Student's t test. Data were expressed as mean ± SEM if not particularly specified. $P < 0.05$ was considered to be significant.

RESULTS

The dominant frequency of the EGG was found to be the same as that of the serosal recording both in the fasting state and after water in 10 patients. It was in the range of 2.46–3.40 cpm. A decrease in the dominant frequency was found in these 10 patients after ingestion of water (3.06 ± 0.11 vs 2.84 ± 0.08 cpm, $P = 0.002$, $N = 10$). One patient showed a substantial amount of dysrhythmia and no obvious dominant frequency was noted. Examples of the frequency change of the gastric slow wave as measured simultaneously from cutaneous and serosal electrodes

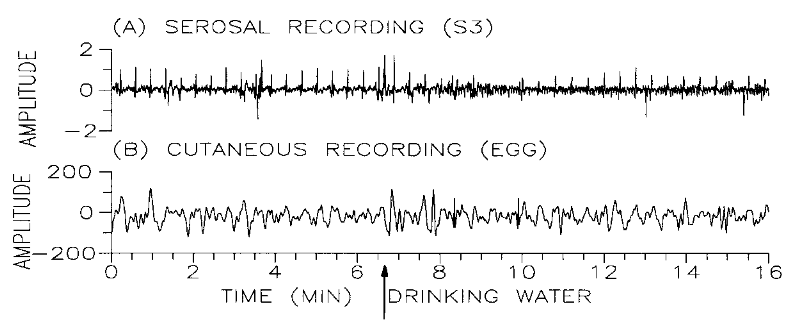

Fig 2. Examples of simultaneous serosal (A) and EGG (B) recordings before and after drinking water showing that there was a simultaneous amplitude decrease in the EGG and serosal recordings after drinking water.

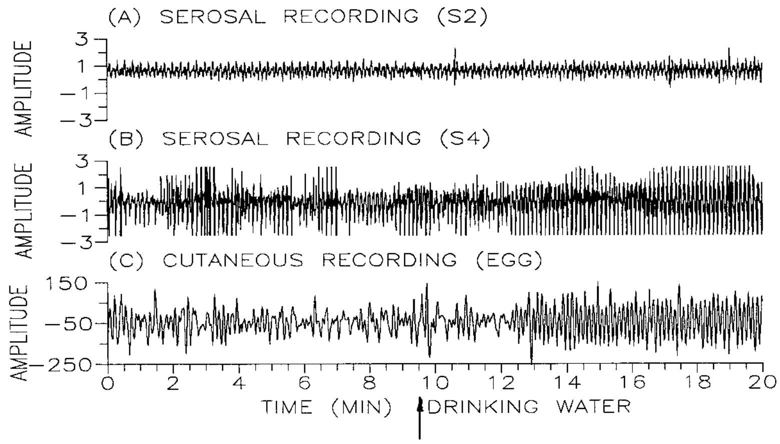

Fig 3. Tachygastria observed in one patient in both serosal and cutaneous recordings both before and after drinking water. (A): Serosal recording from the proximal stomach; (B): serosal recording from the antrum; (C) cutaneous EGG recording.

are shown in Figures 1 and 2. Gastric dysrhythmias lasting for more than 30% of the recording time were observed in three of the 11 patients. One patient had arrhythmias in the prewater state and one in the postwater state. A continuous tachygastria of higher than 4 cpm in both the prewater and postwater states was observed in the third patient (Figure 3). Power spectral analysis of the EGG revealed uncoupled gastric dysrhythmia, ie, the power spectra of the two-channel serosal recordings had different frequency patterns (Figure 4, left panel). The spectral pattern of the EGG was different than either of the serosal recordings. This is because the EGG is a summation of all internal gastric myoelectrical activities. After the ingestion of water, however, the two serosal recordings showed consistent tachygastria and the EGG revealed the same tachygastrical frequency (Figure 4, right panel). Other abnormalities in gastric myoelectrical activity in these 11 patients were also noted and will be reported elsewhere (35).

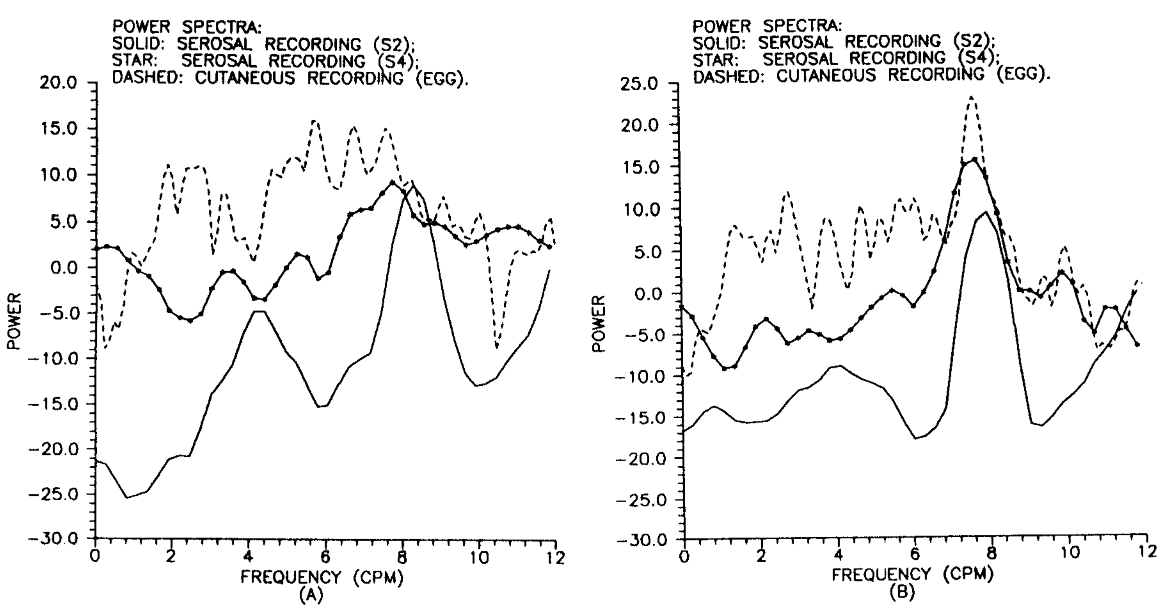

Fig 4. Power spectra of simultaneous serosal and cutaneous signals shown in Figure 3. Left: prewater state; right: postwater state. No obvious dominant frequency was noted in the EGG in the prewater state, while the serosal recordings showed different patterns of gastric dysrhythmia from the EGG. The dominant frequency of the EGG in the postwater state was the same as the serosal recordings both in the proximal stomach and in the antrum (7.6 cpm).

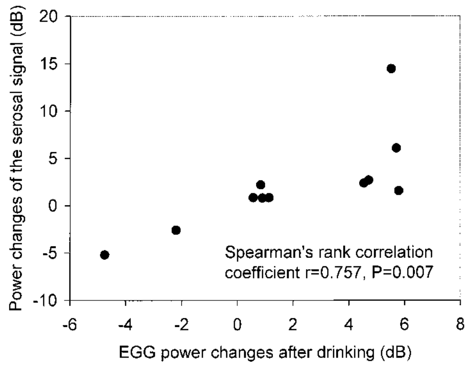

Fig 5. Correlation between postprandial power (amplitude) changes in EGG and serosal recordings (Spearman's rank correlation coefficient $r = 0.757$, $P = 0.007$, $N = 11$).

Spectral analysis of the serosal recording revealed that nine patients showed an increase in the dominant power after ingestion of water while the other two had a decrease (see Figure 5). Consistent results were found in the analysis of the EGG recording. Examples of simultaneous EGG and serosal recordings are presented in Figures 1 and 2. Figure 1A and B present simultaneous serosal and EGG recordings, respectively, 5 min before and 10 min after drinking water in one patient. Figure 2 shows there was an amplitude decrease after water in one patient both in the serosal (Figure 2A) and EGG recordings (Figure 2B). Spectral analysis of the data shown in Figure 2 revealed that after drinking water, the peak power of the EGG decreased (−2.2 dB in Figure 2B) consistent with the power decrease of the serosal recording (−2.6 dB in Figure 2A).

Statistical analysis demonstrated that the dominant power change after water computed from the EGG was correlated with that observed in the serosal recording (correlation coefficient $r = 0.757$, $P = 0.007$, $N = 11$) (Figure 5).

DISCUSSION

Using simultaneous serosal and cutaneous recordings of gastric myoelectrical activity and a computerized spectral analysis method for determining the frequency and power of the gastric slow wave, we found the following: (1) exogenous stimulation of the stomach, such as a drink of water, changed the amplitude of the gastric slow wave, (2) the change of EGG power (amplitude) after water was correlated with the serosal recording of the gastric slow wave, and (3) water also decreased the frequency of the gastric slow wave as measured by serosal electrodes and the EGG could precisely track this change.

The use of simultaneously implanted serosal electrodes as a validation tool of the cutaneous EGG has been well documented (5–8, 36). It is generally accepted that the dominant frequency of the EGG accurately represents the frequency of the gastric slow wave and the cutaneous EGG is also able to track the frequency change of the gastric slow wave due to certain stimulations. In the present study, using the serosal recording as a gold standard, we have confirmed that a liquid meal (water) decreases the frequency of the gastric slow wave. These changes are reflected in the EGG. This finding is consistent with previous studies (6, 24, 37).

It has been proven that the absolute value of EGG amplitude does not seem to be useful since it is related to several factors, such as the position of the electrodes, the distance between the bipolar electrodes, body mass index, the thickness of the abdominal wall of the subject, the preparation of the skin, the characteristics of the recording equipment, and the method of spectral analysis (14, 24, 25, 27, 38, 39). It is generally agreed that only relative changes of EGG power have clinical significance. For example, a postprandial increase of EGG amplitude has been consistently observed (11, 21–24, 39). Three explanations have been given so far for the amplitude increase of the EGG after eating: (1) The postprandial increase in EGG amplitude reflects increased spike activity or gastric contractions (6, 7, 10, 11, 21, 26). (2) The distended postprandial stomach may lie in closer proximity to surface electrodes than the fasted stomach, resulting in an increase EGG amplitude (9, 27, 28). (3) The postprandial EGG amplitude increase was caused by both the distension of the stomach and the increase in gastric contractile activity. This is consistent with previous data that the EGG amplitude increased after water without an increase in contractile activity simultaneously measured by manometry, while a solid meal induced an increase in EGG amplitude and phasic contractions by manometry (24). However, none of these studies addressed the quantitative measurement of the slow-wave amplitude and its relationship with the postprandial change of the EGG amplitude.

In the present study, we found that water ingestion induced changes in slow-wave amplitude, not only increases but also decreases in some cases. Spectral and statistical analyses of simultaneous recordings of gastric myoelectrical activity by cutaneous electrodes and serosal electrodes revealed that the dominant EGG power change after water was correlated with that observed in the serosal recording. To our knowledge, this finding has not been previously reported.

Would the postprandial EGG power decrease in some patients with gastroparesis (19) or unexplained dyspeptic symptoms (17)? Generally speaking, the effect of eating on the EGG amplitude may be attributed to gastric distension, gastric displacement, stimulation of gastric contraction, and change of gastric slow waves. Gastric displacement may increase the distance between the stomach and the electrodes, possibly resulting in a decrease of EGG power. However, studies have shown that this rarely occurs (14). Gastric distension and stimulation of gastric contractions generally increase the power of the EGG. Therefore, the only possible cause for the decrease of EGG power in two patients could be the change of the gastric slow wave, due to either a decrease of its amplitude or a degradation of its regularity, or both. It is believed that the slow wave has to reach a certain threshold in order for spike/second potentials (or contractions) to occur. Certainly, the postprandial amplitude decrease in the gastric slow wave may cause the absence or decrease of spike/second potentials (or contractions), resulting in gastric motility disorders as seen in these gastroparetic patients we studied, and reported in some patients with unexplained dyspeptic symptoms.

In summary, exogenous stimulations, such as ingestion of water, may change the EGG amplitude, which is correlated with that observed in the serosal recording, suggesting that the amplitude change of the gastric slow wave is one of the important factors for the amplitude changes in the postprandial EGG.

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