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GASTROENTEROLOGY

Fasting and postprandial small intestinal slow waves non-invasively measured in subjects with total gastrectomy

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Abstract

Background and Aim: Slow wave is essential to initiate gastrointestinal tract motility. Subjects with total gastrectomy (TG) provide an opportunity to study small intestinal slow wave in the absence of stomach interference. The aims of this study were to determine the origin of 3 cycles per min (cpm) slow wave recorded via electrogastrogram (EGG) and the characteristics of putative small intestinal slow waves in TG subjects.
Methods: Thirty-three subjects with TG (25 male, age: 44–83 years) were consecutively enrolled. In each subject, the myoelectricity-like signals of the gastrointestinal tract were recorded using 3-channel EGG. Fourier transform-based spectral analysis was performed to derive the EGG parameters including dominant frequency/power, % normal rhythm (2–4 cpm), and power ratio.
Results: Neither visual nor spectral analysis of the EGG revealed any waves at a frequency of about 3 cpm. The most frequently observed peaks in the power spectra of all subjects were those at ~1, ~6 and ~11 cpm with occurrences of 97%, 6.1% and 90.9%, respectively. Based on visual analysis of all recorded signals, the ~11 cpm signal was exactly rhythmically recorded rather than the ~1 cpm. The recorded ~11 cpm wave had a frequency of 10.9 ± 1.0 cpm in the fasting state and 10.9 ± 1.3 cpm in the fed state (NS), and a power of 31.5 ± 3.2 dB in the fasting state and 35.2 ± 3.8 dB in the fed state ($P < 0.0001$). None of other factors, including sex, age, and body mass index, had any impact on this ~11 cpm wave.
Conclusions: Small intestinal slow wave can be recorded non-invasively using EGG via cutaneous electrodes in TG subjects. Sex, age and body mass index have no effect on the intestinal slow waves. The power rather than frequency of intestinal slow wave is increased after a solid meal.

Introduction

The stomach is a dynamic organ and coordinated motor activity is required to achieve the functions of food storage or accommodation, mixing and emptying. In addition to the control mechanisms involving central, spinal, enteric nervous and humeral levels, the stomach muscle itself has a myogenic character to mediate motility. Both slow wave (electrical control activity) and spike (electrical response activity) are well-known components of gastric myoelectricity.[1,2] Slow wave, an omnipresent myoelectrical activity, originates from the proximal body of stomach. It reflects the continuous rhythmic change in the membrane potential and propagates distally to the distal antrum with a regular rhythm about 3 cycles per min (cpm) in humans.[3] Physiologically, slow wave triggers the onset of spikes that elicit muscle contraction.[1,2,4] The slow wave is essential to gastric motility including gastric emptying.[2,5] Electrogastrography (EGG) refers to a technique in recording this rhythmic stomach myoelectricity from electrodes positioned on the abdominal skin.[6–8] Noninvasiveness is one of major advantages of EGG.[9,10] Although EGG cannot replace other validated measures to diagnose stomach dysmotility, it remains useful in some motor diseases associated with gastric dysrhythmia.[7,9,11] Computerized spectral analyses are commonly used to obtain various EGG parameters.[8,12,13]

It is of interest what is recorded if the origin of gastric slow waves is removed such as via total gastrectomy (TG). Previous reports indicate that myoelectricity-like rhythm ranging from 1 to 11 cpm can be recorded in TG subjects.[14,15] Similar to the stomach, there is slow wave in the small intestine (SI). The SI slow wave has a frequency of 12 to 9 cpm from the duodenum to the ileum. In normal subjects, the SI slow wave is rarely noticeable on EGG as its amplitude is much lower than that of the gastric slow wave.[16] Because the stomach is totally removed in TG subjects, it provides an opportunity to investigate the putative SI myoelectricity without interference from the stomach.

Using TG subjects as a non-invasive study model, the aims of this study were to investigate (i) the composition of the EGG and the origin of 3 cpm slow waves in the EGG; and (ii) the feasibility of recording SI slow wave using EGG and the characteristics of the putative SI slow waves in the fasting and fed states of TG subjects.

Methods

Subjects

For the study purposes, only individuals who had undergone radical TG for gastric cancer in this hospital with a traceable surgical record were eligible to be enrolled. In addition, we only enlisted those TG subjects with the surgery performed 1 year or more prior to the study. Accordingly, their elapsed times between the TG and the study could be precisely obtained from chart review (mean 5.9 ± 3.3 years, range 1–16 years). However, TG subjects were excluded if they had any of the following: malabsorption; metastasis; tumor (other than gastric cancer)-related terminal stage disease; bacterial overgrowth in the gut; milk intolerance; diabetes; or use of any medications known to alter gastrointestinal motility 1 week prior to the study.

Thirty-three consecutive eligible TG subjects (25 male, eight female; age range 44–83 years) from our gastroenterology clinic were enrolled in the study. All of them had received routine follow-up endoscopy to confirm the status of TG and Roux-en-Y esophagojejunal anastomosis. This project was approved by the ethics committee of this hospital, and written consent was obtained from all subjects before the study.

EGG system

The gastrointestinal myoelectricity was recorded using a homemade three-channel EGG system, which included a signal acquisition module, a notebook PC (Pentium 166 MHz), the power supply and electrodes.[17] Briefly, each of three active electrodes was connected to a common reference electrode placed on the right forearm to record myoelectrical signals.[18] The first electrode was placed at the lower costal margin of the left middle clavicle line, the second at 3 cm to the right of middle point of a line connecting the xiphoid process and umbilicus, and the third at the middle point between the first and second electrodes. The recorded 3-channel signals were preamplified to fit the high impedance of human body. A fourth order active high-pass filter with 0.01 Hz cutoff frequency and a low-pass filter with 0.5 Hz cutoff frequency were installed to filter out unnecessary noises and artifacts. An analog multiplexer processed filtered signals via a 12-bit analog/digital converter card. Then the digitized signals were transmitted to a notebook PC for on-line display and real-time analysis. The host software installed in the PC was written with 'Borland C++ Builder V 1.0 Professional' (Inprise, Scotts Valley, CA, USA) on the Window 95 platform.

The stored signals on the PC were analyzed using a custom-made software.[19] Briefly, smoothed power spectral analysis was used to produce the overall power spectrum during each recording period. The frequency at which the overall power spectrum of the entire recording period displayed a peak power was defined as the dominant frequency (DF). Similarly, the power of DF in the power spectrum was defined as the dominant power (DP).[7] The decibel (dB) unit was used to represent the EGG power. Assuming a sinusoidal signal with an amplitude of A, power P in dB was expressed as $P\ (\mathrm{dB}) = 10 \times \log 10\ (A^2)$. Power ratio (PR) refers the postprandial power change, which was evaluated as the ratio of EGG power in the postprandial state to that of the fasting state (postprandial μV^2/fasting μV^2).[13]

Experimental protocol and myoelectrical recording

Before the measurement, dyspeptic symptoms of each TG subject were assessed. The main symptoms, including nausea, vomiting, anorexia, epigastria pain, epigastria fullness, and early satiety, were noted and scaled according to the following severity scale: grade 0 = not present; 1 = mild, occasional, slightly influencing daily activities; 2 = moderate, often influencing daily activities; 3 = severe, very often, with strong impact on concentration and daily activities.[20]

After an overnight fast, the subject was asked to come to the clinic, to lay quietly on a supine position and not to move, fall asleep or talk throughout the whole recording. In order to minimize the impedance between electrodes, the upper abdominal skin where the electrodes would be placed was cleaned and gently scrubbed until the appearance of redness. Four silver-silver chloride electrodes filled with electrode jelly (Red Dot-2237, 3M, St Paul, MN, USA) were placed on the defined areas.

The fasting EGG was recorded for 30 min. After the basal recording, the subject was asked to consume within 5 min a standard light meal of 250 mL milk and a cake. This meal consisted of 347 kCal with the following compositions: carbohydrate 51 g; protein 13.2 g; and fat 10 g. Immediately after the meal, a 30-min postprandial recording was made and the individual was once again asked to remain still and quiet.

Statistics

Results were expressed as mean ± SD. Categorical data were analyzed using chi-squared test. Numerical data were analyzed using two-tailed paired Student's *t*-test. Linear regression was used to study the correlation coefficient between two variables. A *P*-value of <0.05 was considered significant.

Results

Based on power spectral analysis, we found that most spectral peaks of the recorded EGG signals were obviously observed at ~1 cpm. Figure 1 illustrates the typical spectrum of most TG subjects. In addition, there was another power spectral peak at ~11 cpm appearing in most TG subjects. In a few TG subjects, there was also a power spectral peak at ~6 cpm (Fig. 2). Table 1 shows the numbers (or percentage) of study subjects showing spectral peaks at various frequencies (1, 6 and 11 cpm) in this 3-

Table 1 Occurrences of various spectral peaks computed from smoothed power spectral analysis based on three cutaneously placed electrodes on upper abdomen of 33 total gastrectomy subjects

Channel†	~1 cpm [*n* (%)]		~6 cpm [*n* (%)]		~11 cpm [*n* (%)]	
	Fasting	Postprandial	Fasting	Postprandial	Fasting	Postprandial
Channel 1	30 (90.9)*	31 (93.9)	0 (0)	0 (0)	27 (81.8)**	26 (78.8)
Channel 2	32 (97.0)*	30 (93.8)	0 (0)	0 (0)	28 (87.9)**	24 (87.9)
Channel 3	19 (57.7)*	28 (84.8)	2 (6.1)	2 (6.1)	20 (60.6)**	21 (63.6)

†Channel 1 was placed at the lower costal margin of the left middle clavicle line. Channel 2 was placed at 3 cm to the right of the middle point of the line connecting the xiphoid process and umbilicus. Channel 3 was placed at the middle point of the line between channels 1 and 2.
$^*P < 0.001$; $^{**}P < 0.05$ compared within three channels.

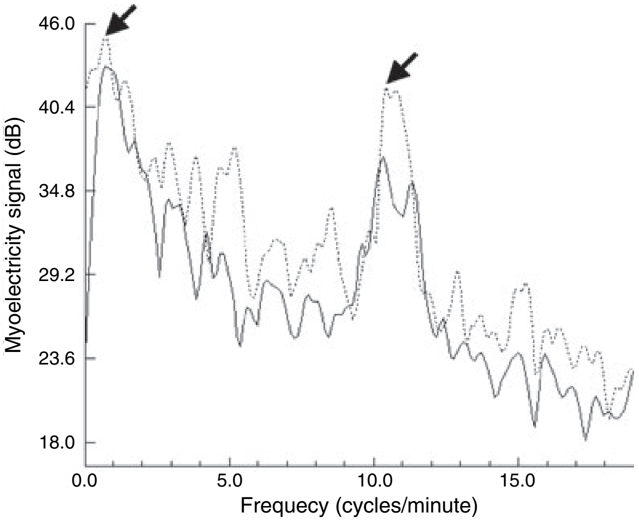

Figure 1 Smoothed power spectrum analysis of recorded myoelectricity-like signals of a subject with total gastrectomy. Power peaks of ~1 cpm and ~11 cpm (arrows) were obviously present. (—) Fasting recording; (- - -) postprandial recording.

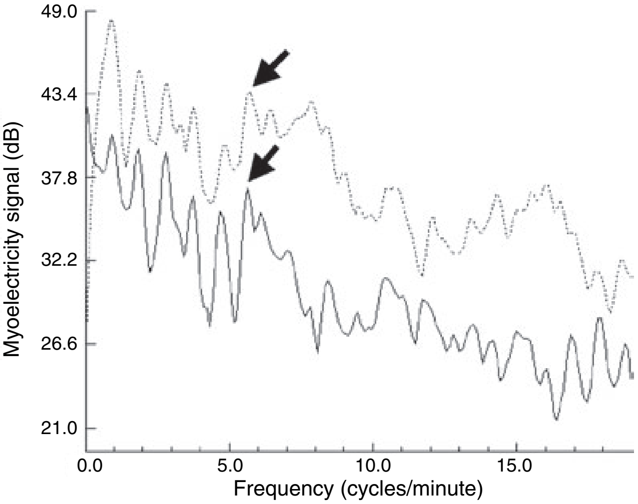

Figure 2 Smoothed power spectrum analysis of recorded myoelectricity-like signals of another subject with total gastrectomy. Apart from the power peak of ~1 cpm, the peaks of ~6 cpm were also present (arrows). (—) Fasting recording; (- - -) postprandial recording.

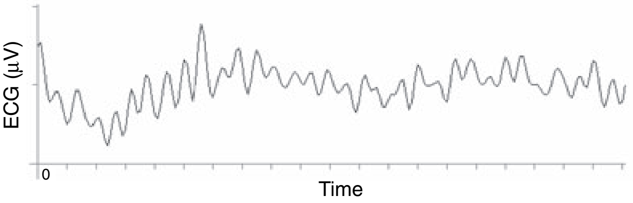

Figure 3 Visual analysis of raw electrogastrographic (EGG) recording of a subject who received total gastrectomy. *X*-axis scale is 10 s and *y*-axis scale is 200 μV. The ~1 cpm drift superimposes on the ~11 cpm myoelectricity-like rhythm.

channel EGG. It can be seen that the spectral peak at ~11 cpm was present in 60.6–81.8% of the subjects among the three channels in the fasting state, and its presence in Channel 3 was significantly lower; however, this difference was not noted in the fed state. Similar findings can be noted from this table regarding the spectral peak at ~1 cpm. However, spectral peaks at ~6 cpm were completely absent in Channels 1 and 2, and rarely observed (6.2% of subjects) in Channel 3 in both fasting and fed states.

The ~11 cpm myoelectricity-like rhythm was recorded in 30 (90.9%) of the 33 subjects based on the visual and spectral analyses. The mean frequency of the waves among these 30 subjects was 10.9 ± 1.0 cpm in the fasting state and 10.9 ± 1.3 cpm in the fed state (NS). Their corresponding power was 31.5 ± 3.2 dB in the fasting state and increased to 35.2 ± 3.8 dB in the fed state ($P < 0.0001$). The PR was 3.27 ± 3.23 (0.29–16.37). For the two subjects showing a power peak of ~6 cpm, the fasting frequencies were 7.5 cpm and 5.6 cpm, their corresponding powers were 33.2 and 37.1 dB, respectively. The fed frequencies were 6.6 cpm and 5.7 cpm and powers were 34.4 dB and 43.6 dB, respectively. In contrast, the ~1 cpm spectral peak was noted in almost all subjects (32, 97%), and the mean fasting and postprandial frequencies were 0.83 ± 0.21 cpm and 0.81 ± 0.17 cpm, respectively (NS), and the corresponding powers were 41.8 ± 3.7 dB and 43.4 ± 3.7 dB, respectively ($P < 0.01$) with a PR value of 1.88 ± 1.42 (0.34–6.21).

Further visual analysis of the recorded signals revealed that the ~11 cpm signal but not the ~1 cpm signal was exactly rhythmically recorded (Fig. 3). Thus we believed that the ~1 cpm obtained from the power spectrum was a low frequency drift superimposed on the myoelectrical-like signal of ~11 cpm. For the subsequent characteristic analysis, we only evaluated the signal of ~11 cpm.

Table 2 Correlation coefficients of various demographic characteristics of 33 total gastrectomy subjects presented against their power spectral parameters of myoelectricity-like signal at ~11 cpm

Parameter	Age (years)	Body mass index (kg/m^2)	Elapsed time since operation (years)	Total symptom score
Frequency				
Fasting	–0.27	–0.15	0.22	–0.34
Postprandial	–0.20	–0.29	0.41*	–0.01
Power				
Fasting	0.18	–0.25	0.27	0.02
Postprandial	0.29	–0.18	0.05	0.11
Power ratio	0.12	–0.08	–0.04	0.17

*$P < 0.05$.

In the 30 subjects with an obvious power peak of ~11 cpm, the fasting frequencies of 23 men and 7 women were 10.8 ± 1.0 and 11.1 ± 1.0 cpm, respectively (NS), and their corresponding powers were 32.1 ± 3.2 and 29.6 ± 2.7 dB, respectively (NS). In the postprandial recording, the frequencies were 10.8 ± 1.4 and 11.2 ± 0.7 cpm, respectively (NS), and the corresponding powers were 35.8 ± 4.1 and 32.6 ± 2.3 dB, respectively (NS). The PR were 3.40 ± 3.54 and 2.85 ± 2.02, respectively (NS). Regarding the influence of smoking, the fasting frequencies of 4 smokers and 26 non-smokers were 11.7 ± 1.6 and 10.7 ± 0.8 cpm, respectively (NS). Their corresponding powers were 33.7 ± 1.4 and 31.2 ± 3.3 dB, respectively (NS). The frequencies in the fed state were 12.0 ± 1.9 and 10.7 ± 1.1 cpm, respectively (NS) with corresponding powers of 34.7 ± 3.2 and 35.8 ± 4.1 dB, respectively (NS). The PR were 1.71 ± 1.15 and 3.51 ± 3.39, respectively (NS).

Twenty-five of the 30 subjects with ~11 cpm waves reported dyspeptic symptoms ranging from 1 to 9 (mean 2.5 ± 2.3) and the correlation of the parameters of ~11 cpm signals with various factors was analyzed in these subjects. Table 2 illustrates the correlation coefficients of age, body mass index, elapsed time from the TG to the study and the total symptom score against the frequency and power of the ~11 cpm signals. Only elapsed time from the TG to the study showed a positive correlation with the postprandial frequency ($P < 0.05$) of the ~11 cpm waves. Neither age, body mass index nor the total symptom score exhibited any correlation with any parameters of the ~11 cpm waves.

Discussion

Using a homemade EGG and smoothed power spectral analysis, our study showed obvious spectral peaks at ~1 and ~11 cpm in the TG subjects. Unlike our previous study conducted on normal subjects with intact stomach,[17] there was a complete absence of a 3 cpm wave in any of the recordings of TG subjects. Visual analysis of the raw tracings suggested the true presence of only ~11 cpm but not ~1 cpm myoelectricity-like rhythm. There was a significant postprandial increase in the power of this ~11 cpm rhythm.

For the best recording, stomach slow wave should be directly measured from serosal or mucosal electrodes.[10,21] However, these approaches are too invasive for clinical use. EGG is designed to record gastric slow waves via cutaneously placed electrodes. In the method of EGG, as the recording electrodes are away from the targeted signal source, background noises and interference from organs other than the stomach are always recorded.[8] Accordingly, visual analysis is impractical and computerized spectral analysis is commonly applied, which is capable of separating the gastric signal from the background noises and interference from organs, such as small intestine and colon.[7,8,13] Our observation of the complete absence of 3 cpm wave in the TG subjects indicates that the usual ~3 cpm rhythm recorded in subjects with an intact stomach is exactly of gastric origin. Similar findings were also reported in a few previous studies.[14,15]

The ~11 cpm myoelectricity-like rhythms recorded in the TG subjects in this study are believed to be small intestinal in origin. In general, EGG has the ability to record all electrical signals within the human body including stomach, small intestine, colon and unexpected noises.[22] Under normal conditions, EGG is designed to record only gastric myoelectricity and to minimize other noises and interferences. In contrast, TG subjects appear to serve as an excellent model for us to study whether the putative myoelectricity-like rhythms from the SI and colon can be recorded using EGG because the gastric signal, which is much stronger than those of the SI and colon, is already removed.

Small intestinal myoelectrical activity is characterized by the membrane potential fluctuations of 3–15 mV, oscillating at 11–12 cpm in the proximal SI.[23] Extracellular recordings of SI slow waves are sinusoidal or of rapid biphasic deflections.[23] Accordingly, the Fourier transform, the fundamental calculation used in this study, is well suited for the spectral analysis of sinusoidal slow waves recorded in EGG.[24] In addition to a DF of 3.1 cpm recorded from the gastric remnants in patients receiving Billroth II and vagotomy, Schaap *et al*.[25] measured another myoelectricity-like rhythm of 10.5 cpm, which was considered to be of SI origin. In another study, a rhythm of 10–11 cpm recorded in subjects with intact stomach was reported by Yoshitomi *et al*.[26] using electrogastroenterography (EGEG). In previous studies of only TG subjects, similar 11 cpm waves were recorded via EGG and these waves were believed to be from the jejunum as the Roux limb of the jejunum was very close to the recording electrodes in a supine position.[14,15,27] Using a homemade EGG system designed to record stomach myoelectricity, we also recorded these ~11 cpm waves, which were confirmed by the visual analysis of the original tracing as well as the spectral analysis. We believe that this rhythm most likely originated from the jejunum.

Our EGG system indicated that channel 3 had the least chance to record the SI myoelectrical signal in the fasting state. We suggest that the electrode position for this channel was too far away from the origin of the SI slow wave and perhaps the SI slow wave was too weak to be recorded in the fasting state. Similar to the postprandial findings with the gastric slow wave,[28] the present study indicated that there was a significant postprandial increase in the amplitude (or power) but not the frequency of the SI myoelectricity. In a rodent study with serosally placed electrodes, it was found that the fasting jejunal slow wave amplitude correlated well with migrating motor complex (MMC).[29,30] In contrast, the jejunal postprandial myoelectrical amplitude was reported be both diminished[29] and increased.[30] As the powerful phase III (10 min) constitutes a small portion of the MMC in human subjects,[23] we believe that the 30 min fasting recording in the current study had a small chance of coinciding with phase III of the jejunal MMC, leading to a lower amplitude. The postprandial increase of the SI slow wave amplitude observed in our study supports the observation of enhanced fed myoelectrical amplitude previously reported by Branstrom *et al*.[30] This SI slow wave power enhancement after meal is a unique aspect of our study as previous studies conducted on TG patients did not specially focus on EGG power expression.[14,15]

Age and sex were reported to have a subtle influence on the frequency of the gastric slow wave; [31] however, this was not confirmed in other studies.[18,32] Our study found that neither the frequency nor power of the putative SI slow myoelectricity was altered by age or sex. Similarly, human SI motility was previously reported to be unchanged in elderly subjects.[33] In contrast to the influence of body mass on the DP of the gastric slow wave,[18] the present study indicated that body mass did not alter jejunal slow wave, neither in the fasting state nor in the fed sate. It probably means that human SI slow wave is very stable without any influence from demographic factors. We also found that dyspepsia was common in TG subjects although it was mild in nature. With regard to the recorded dyspeptic symptoms, no correlation between symptomatic scores and jejunal myoelectricity was identified in our study, which was in an agreement with a previous study by Schaap *et al*.[25]

It is of interest whether the spectral peak at ~1 cpm observed in this study truly reflected the myoelectrical activity from the colon. Pezzolla *et al*.[14,22] reported that EGG occasionally recorded a colon myoelectrical activity of 0.5–2.5 cpm in TG subjects for a short time; however, it had little influence on the spectral analysis. In contrast, Homma *et al*.[15] recorded 3 cpm activity in TG patients, which they believed to be colon in origin. In our study, we did not find any myoelectricity of ~3 cpm from any channels in any TG subjects. The visual analysis of the tracings revealed a clear drift of ~1 cpm superimposed on the rhythm of ~11 cpm (Fig. 3). In terms of the automatic spectral analysis, some pitfalls are often ignored by examiners. For example, the very low frequency of EGG signals are often caused by factors inherent to the recording rather than true myoelectricity, because neither the stomach nor other human organs have the ability to produce such a ~1 cpm signal.[8,34] Taking this notion and the visual analysis of the raw recording together, we would exclude the colon origin of this ~1 cpm activity.[34] It is well known that colon slow wave frequency and its propagation are highly variable, which is partly attributed to the lower density of nexuses in the colon;[23] for example, the reported frequencies of colon slow wave range from 2.5 to 12 cpm.[23,24,35,36]

In conclusion, a 3 cpm wave is completely absent in the EGG recording of TG subjects, confirming its gastric origin. Slow wave of SI can be non-invasively recorded using EGG in TG subjects. The postprandial response of the SI slow waves is similar to that of the gastric slow wave; that is, a significant increase in amplitude. Sex, age, or body mass index does not seem to alter SI slow waves and the SI slow wave rhythm does not seem to be related to dyspeptic symptoms.

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