Hindawi
GastroHep
Volume 2023, Article ID 6902635, 8 pages
https://doi.org/10.1155/2023/6902635

Research Article

Visualized Quantitative Evaluation of Gastrointestinal Activity in Healthy Volunteers Using a Noninvasive Single-Channel Electroamplifier

Gen Aikawa,[1] **Misaki Kotani**,[2] **Hideaki Sakuramoto**,[3] **Akira Ouchi**,[1] **Mitsuki Ikeda**,[2,4] **Tetsuya Hoshino**,[4] **Nobuyuki Araki**,[5] **Yuki Enomoto**,[4] **Nobutake Shimojo**,[4] **and Yoshiaki Inoue**[4]

[1]*Department of Adult Health Nursing, College of Nursing, Ibaraki Christian University, 6-11-1 Omika, Hitachi, Ibaraki, Japan*
[2]*Pediatric Intensive Care Unit, University of Tsukuba Hospital, 2-1-1 Amakubo, Tsukuba, Ibaraki, Japan*
[3]*Department of Critical Care and Disaster Nursing, Japanese Red Cross Kyushu International College of Nursing, 1-1 Asty, Munakata, Fukuoka, Japan*
[4]*Department of Emergency and Critical Care Medicine, Faculty of Medicine, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, Japan*
[5]*Department of Neurology, Graduate School of Medicine, Chiba University, 1-8-1 Inohana Chuoku, Chiba City, Chiba, Japan*

Correspondence should be addressed to Gen Aikawa; gethoon@gmail.com

Received 25 May 2023; Accepted 28 August 2023; Published 14 September 2023

Academic Editor: Sreedhari Thayalasekaran

Background. Electrogastrography and electroenterography are noninvasive methods for measuring gastric and intestinal electrical activities, respectively. Few studies have measured electroenterography in healthy humans; however, no studies have measured electrogastrography and electroenterography simultaneously. This study was performed to provide basic electrogastrography and electroenterography data for comparison with future studies in patients. *Methods*. Simultaneous preprandial and postprandial measurements of electrogastrography and electroenterography were taken for 30 min each in 50 healthy volunteers. Power spectrum analysis was performed to calculate dominant frequency, dominant power, and power ratio. *Results*. Gastric and small intestinal dominant frequencies were not significantly different between preprandial and postprandial periods. In preprandial and postprandial periods, normogastria was seen in 49 (98%) and 44 (88%) patients ($p = 0.063$), bradygastria in 1 (2%) and 6 (12%) patients ($p = 0.063$), and tachygastria in 0 (0%) patients, respectively. Dominant power was significantly increased in the stomach (828 [460–3203] μV^2 vs. 1526 [759–2958] μV^2, $p = 0.016$) and small intestine (49 [27–86] μV^2 vs. 68 [37–130] μV^2, $p < 0.001$). The power ratio was 1.6 (0.9–2.5) in the stomach and 1.4 (1.0–2.5) in the small intestine. Body mass index showed a negative correlation with the stomach and small intestinal dominant power in preprandial and postprandial periods ($r_s = -0.566$, $p < 0.001$; $r_s = -0.534$, $p < 0.001$; $r_s = -0.459$, $p < 0.001$; and $r_s = -0.529$, $p < 0.001$, respectively). The Bristol Stool Form Scale correlated positively with the small intestinal power ratio ($r_s = -0.430$, $p = 0.002$). *Conclusion*. There was no change in frequency in the stomach or small intestine, but power significantly increased in both the stomach and small intestine.

1. Introduction

The gastrointestinal tract is an important organ and is responsible for the digestion of food, absorption of nutrients, and excretion of waste products. When gastrointestinal motility is impaired anywhere from the esophagus to the anus, symptoms such as indigestion, nausea, vomiting, bloating, constipation, abdominal pain, and diarrhea may occur, potentially reducing the patient's quality of life. Gastrointestinal motility occurs as a result of contraction and

relaxation of smooth muscles, which involves the interaction of many cell groups, including cells of the enteric nervous system, interstitial cells of Cajal (ICC), and platelet-derived growth factor receptor alpha-positive cells [1, 2].

ICC form a network throughout the gastrointestinal tract from the esophagus to the colon and function as a pacemaker in gastrointestinal motility [3]. The ICC generate spontaneous and rhythmic electrical activity called slow waves, which are transmitted to smooth muscles, resulting in their spontaneous contraction [4]. ICC are reduced or degenerated in patients with gastrointestinal diseases such as gastroparesis, ulcerative colitis, Crohn's disease, slow transit constipation, and gastrointestinal motility disorders associated with diabetes mellitus [5–9].

The frequency of slow waves varies with the site of the gastrointestinal tract, with slow waves occurring at a basic rhythm of approximately 3 cycles per minute (cpm) in the ICC of the stomach, 9–12 cpm in the small intestine, and 2–6 cpm in the large intestine [10, 11]. Gastric slow waves can be dysrhythmic; bradygastria is defined as slow waves slower than 2 cpm and tachygastria as slow waves faster than 4 cpm. Small intestinal slow wave dysrhythmias have not been observed in humans. Gastrointestinal electrography is capable of measuring the slow wave and includes electrogastrography (EGG) and electroenterography (EEnG) [10, 12, 13].

EGG is a noninvasive technique that monitors gastric electrical activity using electrodes placed on the abdominal surface. Previous studies have shown a good correlation between skin surface EGG recordings and electrical signals recorded from gastric serosal leads [14, 15]. Studies using EGG have shown a higher rate of gastric dysrhythmias and lower ratios of preprandial and postprandial gastric contractility parameters in patients with gastrointestinal disorders such as gastroparesis, chronic unexplained nausea and vomiting, and functional dyspepsia compared to healthy volunteers [16–18]. EEnG, similar to EGG, monitors electrical activity in the small intestine using electrodes placed on the abdominal surface, but few studies have been conducted in humans, and data from healthy volunteers are lacking [19].

This study was aimed at simultaneously assessing the electrical activity of the stomach and small intestine in healthy volunteers using EGG and EEnG and at providing basic data for comparison with future studies in patients.

2. Methods and Materials

2.1. Participants. This study was approved by the institutional review board of the University of Tsukuba (approval #R03-039). The study was registered in the University Hospital Medical Information Network Clinical Trials Registry on July 1, 2021 (UMIN 000044720). All participants provided written informed consent prior to the study, in accordance with the Declaration of Helsinki.

This experimental study recruited 50 healthy volunteers aged 20–65 years (25 men and 25 women). Exclusion criteria were gastrointestinal disorders, autonomic neuropathy, diabetes mellitus, and gastrointestinal peristalsis medication usage within 48 h. Data were collected on age, sex, height, weight, body mass index (BMI), gastrointestinal electrical activity, time since last meal, and stool properties. The participants assessed stool properties using the Bristol Scale Form Scale (BSFS) score [20, 21].

2.2. Procedure. To prepare for the study, participants fasted for at least 4 h and drank no water for at least 2 h according to the guide [10]. Measurements were taken for 30 min in a preprandial state and 30 min in a postprandial state. Participants were instructed to lie in the supine position with minimal body movement. They were also instructed not to talk, sleep, or breathe deeply during all processes of measurement.

After the preprandial measurement, each participant consumed a meal (rice balls) of 250–400 kcal in approximately 10 min. Subsequently, the measurements were performed in the postprandial state, paying attention to the points mentioned above.

2.3. Electrode Placement. Ag/AgCl adhesive gel for electrocardiography was used as the disposable electrode (Vitrode F; Nihon Kohden, Japan). Four surface electrodes, a reference electrode, and a ground electrode were placed on the abdominal skin surface. The electrode placement sites for EGG and EEnG are shown in Figure 1. To measure the electrical signals in the stomach, an electrode was placed 8 cm above the navel along the line connecting the navel and sternum, with a second electrode placed 35° to the upper left and 8 cm away from it [22]. For the small intestine, based on the results of the preliminary study, two electrodes were placed 2.5 cm above the umbilicus, 5 cm apart, symmetrically at the umbilicus (Appendix I–V).

2.4. Recording Setting. We used a biological recording device (Polymate Pocket MP208; Miyuki Giken, Japan) to measure at a sampling rate of 500 Hz. Gastrointestinal electrical activity is 1–9 cpm in the stomach and 9–12 cpm in the small intestine [10, 23]. In addition to these fundamental frequencies, harmonic recordings are recommended [10]. Hence, the frequency setting during data collection was in the range of 1 to 60 cpm (or 0.016 to 1 Hz).

2.5. EGG and EEnG Data Analysis. EGG and EEnG data were analyzed using data-compatible low-frequency analysis software (Low Frequency Analysis Pro; NoruPro Light Systems, Japan). Power spectral analysis was performed for each EGG and EEnG segment using a fast Fourier transform. Power spectral analysis is the most common analytical method for quantifying slow wave variability in the gastrointestinal tract. This method can convert the time domain series data into the frequency domain and generate a spectrum. A running spectral analysis was performed, for which a fast Fourier transform was applied to consecutive 409.6 s signal stretches with approximately 80% of overlap. Dominant frequency (DF) and dominant power (DP) were used as indicators of gastrointestinal electrical activity. DF is the frequency that represents the peak power in the overall power spectrum. DP is the value corresponding to DF from the spectrum and is expressed in μV^2. For EGG, gastric DF was defined as the frequency of the stomach showing peak power in the range of 1–9 cpm [10, 24, 25]. The frequency

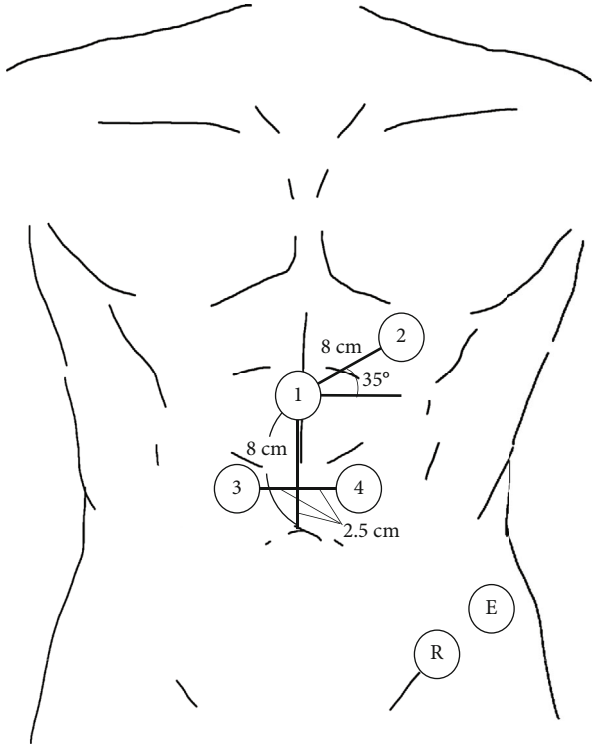

Figure 1: Electrode placement sites for EGG and EEnG. EGG: electrogastrography; EEnG: electroenterography.

ranges were classified into bradygastria (1–2 cpm), normogastria (2–4 cpm), and tachygastria (4–9 cpm).

For EEnG, small intestinal DF was defined as the frequency of the small intestine showing peak power in the range of 9–12 cpm, according to the typical intestinal frequency in different small intestinal segments [10]. DF and DP for each segment were produced from a 30 min running power spectral analysis where preprandial and postprandial values were averaged. Power ratio (PR) is the ratio of power before and after the intervention. A ratio > 1.0 reflects an increase in gastric contractility due to the intervention, and a ratio < 1.0 reflects a decrease in gastric contractility [10, 23].

Gastric and small intestinal DF and DP and classification of gastric DF were compared in both preprandial and postprandial periods. Additionally, we confirmed the correlation between the participants' characteristics and each parameter to identify factors that influence gastrointestinal electrical activity.

2.6. Statistics. All continuous data were tested for normality, but normality was not found. Therefore, descriptive data are expressed as numbers and percentages and continuous data as median and interquartile ranges (IQR). For continuous variables, the Wilcoxon signed-rank test was used. Correlations were calculated using Spearman's rank correlation coefficient. Differences with p values of < 0.05 were considered statistically significant. All analyses were conducted with IBM SPSS Statistics 27 (IBM Corp., Armonk, NY, USA).

Table 1: Participants' baseline data.

Variables	$n = 50$
Male sex n (%)	25 (50)
Age years, median (IQR)	34 (27–42)
Height cm, median (IQR)	166 (158–172)
Weight kg, median (IQR)	60 (51–68)
BMI kg/m^2, median (IQR)	21.5 (20.3–23.5)
Time since last meal hours, median (IQR)	5.0 (4.5–11.3)
Time since last defecation hours, median (IQR)	11.0 (5.0–20.0)
Bristol Stool Form Scale score, median (IQR)	4 (4–4)

BMI: body mass index; IQR: interquartile range.

3. Results

3.1. Participants' Characteristics. A total of 52 participants were recruited, but two participants whose EGG data were not suitable for analysis were excluded, and 50 participants were finally analyzed. The participants included 25 (50%) men with a median age of 34 (IQR 27–42) years and median height of 166 (158–172) cm. Median weight was 60 (51–68) kg, while BMI was 21.5 (20.3–23.5) kg/m^2. The time since last meal was 5.0 (4.5–11.3) h, while the time since last defecation was 11.0 (5.0–20.0) h. The median BSFS score as recorded by participants was 4 (4–4) (Table 1).

3.2. Gastrointestinal Electrical Activity. Figure 2 shows a representable example of a running power spectrum of EGG. The horizontal axis represents frequency, the vertical axis represents power, and the depth axis represents the passage of time. It can be seen that DP increases significantly after meal ingestion.

Gastric DF was not significantly different between preprandial and postprandial periods (3.0 [2.8–3.1] cpm vs. 3.0 [2.8–3.2] cpm, $p = 0.466$). Small intestinal DF was also not significantly different between preprandial and postprandial periods (10.4 [10.1–10.7] cpm vs. 10.2 [9.8–10.6] cpm, $p = 0.065$) (Figure 3(a)).The mean gastric DF classification was as follows: in the preprandial period, bradygastria was seen in 1 (2%), normogastria in 49 (98%), and tachygastria in 0 (0%) participants. In the postprandial period, bradygastria was seen in 6 (12%), normogastria in 44 (88%), and tachygastria in 0 (0%) participants ($p = 0.063$). Six (12%) participants had gastric DF decrease of more than 30% (Figure 4).

Gastric DP significantly increased from the preprandial to postprandial period (828 [460–3203] μV^2 vs. 1526 [759–2958] μV^2, $p = 0.016$). Small intestinal DF also significantly increased from the preprandial to postprandial period (49 [27–86] μV^2 vs. 68 [37–130] μV^2, $p < 0.001$) (Figure 3(b)). PR between preprandial and postprandial periods in the stomach and small intestine were 1.6 (0.9–2.5) and 1.4 (1.0–2.5), respectively.

3.3. Correlations between Characteristics and Parameters of EGG and EEnG. Correlations between participant characteristics and parameters of EGG and EEnG are shown in

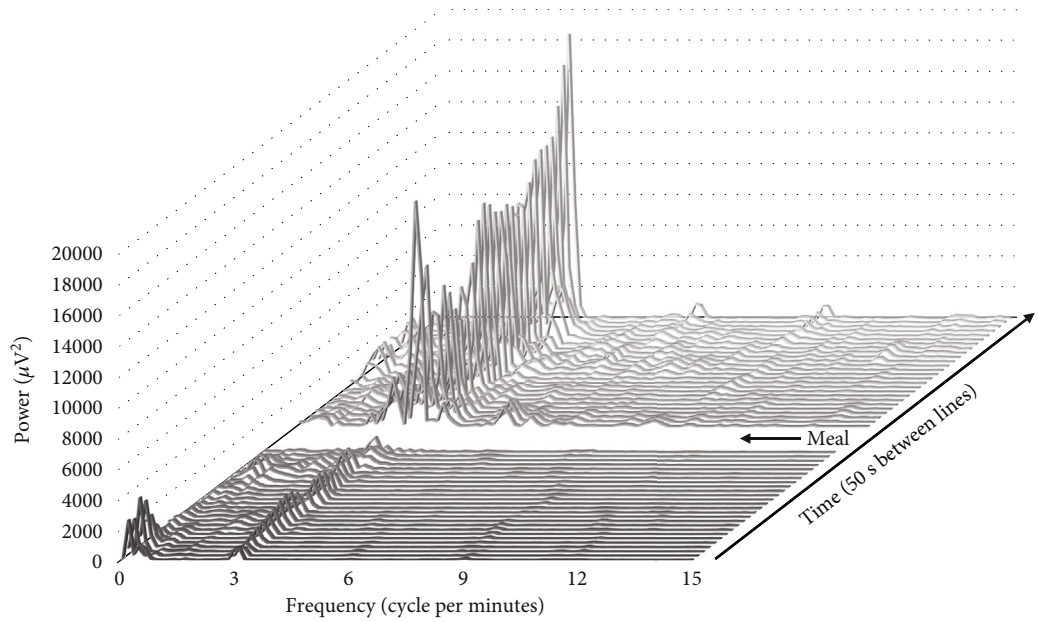

Figure 2: Example of running power spectrum of EGG in a healthy individual. The horizontal axis is frequency, vertical axis is power, and depth axis is time. DP increases following meal intake. EGG: electrogastrography; DP: dominant power.

Table 2. Time since last meal and gastric and small intestinal DF in the preprandial period showed a weak negative correlation ($r_s = -0.341$, $p = 0.015$, and $r_s = -0.348$, $p = 0.013$, respectively). BMI was negatively correlated with gastric and small intestinal DP in both preprandial and postprandial periods ($r_s = -0.566$, $p < 0.001$; $r_s = -0.534$, $p < 0.001$; $r_s = -0.459$, $p < 0.001$; and $r_s = -0.529$, $p < 0.001$, respectively). BSFS and PR of the small intestine showed a weakly positive correlation ($r_s = -0.430$, $p = 0.002$).

4. Discussion

In this study, we compared the electrical activity of the stomach and small intestine between preprandial and postprandial periods in healthy volunteers. Both gastric and small intestinal DF did not change between preprandial and postprandial periods in healthy volunteers. However, there was a significant increase in both gastric and small intestinal DP between preprandial and postprandial periods. In addition, time since last meal and premeal DF, BMI and DP, and BSFS and PR were correlated.

The normal range of gastric DF in healthy individuals is reported to be 2–4 cpm, and the results of this study are generally consistent with this [10, 24, 25]. However, 2% of the participants had bradygastria despite being healthy, with bradygastria increasing to 12% postprandially. Gastric DF was reduced by more than 30% for some of the participants. Gastric mechanoreceptors may have been activated by distension of the stomach due to the meal, triggering dysrhythmias via non-5-hydroxytryptamine-3, non-prostaglandin-dependent, and noncholinergic pathways [25, 26]. Gastric DP increased significantly between preprandial and postprandial periods, similar to previous studies [27, 28]. The reason may be that in addition to the accelerated contraction of the stomach by the meal, the distance between the stomach and the electrode was shortened by the distension of the stomach due to the meal [26, 29].

Although there are few studies measuring noninvasive EEnG, they have been performed in healthy individuals and following total gastrectomy [12, 19]. Since no studies have measured the preprandial and postprandial EEnG in healthy individuals, only premeal parameters can be compared. The results for DF of healthy individuals were consistent with those of the present study [19]. In patients who underwent total gastrectomy, there was no significant change between preprandial and postprandial DF, while DP was significantly increased after meals, similar to the results of the present study [12]. These previous studies are similar to this study with regard to electrode placements. The median PR was lower in this study, which may have been influenced by differences in diet, but the values were within the range reported in these studies [10, 23, 29].

Interestingly, time since last meal and preprandial DF showed a negative correlation, but since 98% of preprandial DF was in the normal range, it is impossible to show any implications. It may be that the incidence of bradygastria may be higher in patients with gastrointestinal problems or in patients who have been fasting for a long period of time. BMI correlates negatively with preprandial and postprandial gastric and small intestinal DP, consistent with the results of previous studies [28]. This may be due to the distance between the stomach and the electrodes being increased by the abdominal wall. However, DP is susceptible to other factors besides BMI, such as skin conductance and differences in stomach shape, and should not be treated in isolation. Therefore, PR showing changes in DP due to intervention should be considered together [23]. The BSFS and PR of the small intestine showed a weak positive correlation. This may suggest that excessive intestinal peristalsis causes soft stools to be excreted without fully absorbing water. However, since

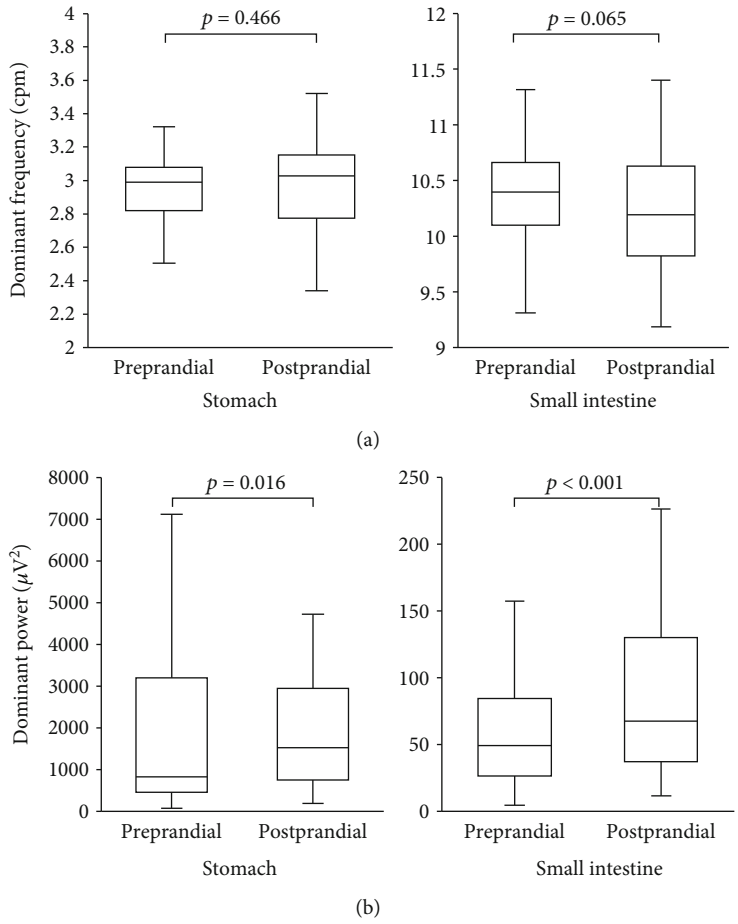

Figure 3: Preprandial and postprandial changes in DF and DP in the stomach and small intestine. Shown is the change in (a) DF and (b) DP in the stomach and small intestine in preprandial and postprandial periods. DF did not change, but DP increased significantly in both the stomach and small intestine. DF: dominant frequency; DP: dominant power.

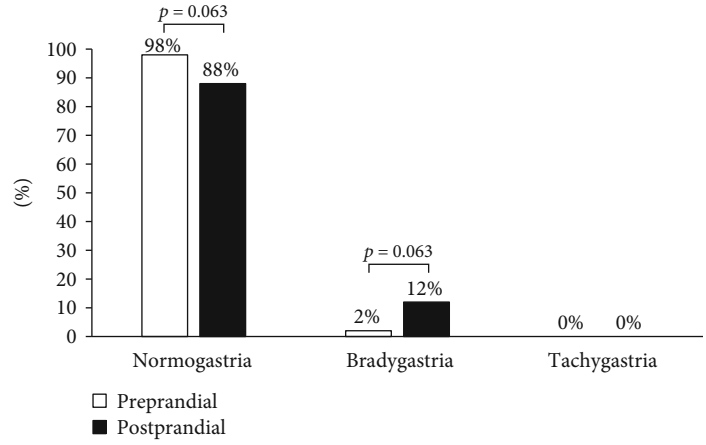

Figure 4: Changes in classification of gastric DF before and after meals in healthy individuals. White bars indicate preprandial and black bars indicate postprandial periods. There was no significant change in the proportion of normogastria and bradygastria in preprandial and postprandial periods. No tachygastria was noted. DF: dominant frequency.

it is mainly the large intestine that determines stool properties, caution should be exercised in interpreting the results because there may be a relationship between the electrical activity of the large intestine and fecal characteristics. Hence, further study of the electrogram of the large intestine is also needed.

In clinical practice, it may be possible to assess a patient's gastrointestinal motility function using EGG and EEnG. In patients whose defecation must be controlled, healthcare professionals check the status of defecation and administer gastrointestinal peristalsis stimulants. Real-time visualization of

Table 2: Correlation coefficients between characteristics of healthy volunteers and gastrointestinal electrical activity parameters.

Parameter	Male sex	Age	BMI	Time since last meal	Time since last defecation	Bristol Stool Form Scale
Gastric DF						
Preprandial	0.062	-0.043	0.051	-0.341*	-0.024	-0.102
Postprandial	0.007	-0.002	-0.155	-0.272	-0.060	-0.064
Gastric DP						
Preprandial	-0.234	-0.109	-0.566**	0.117	-0.064	-0.143
Postprandial	-0.068	-0.219	-0.534**	0.042	-0.049	-0.009
Power ratio	0.229	0.014	0.046	0.000	0.123	0.132
Small intestinal DF						
Preprandial	-0.060	0.018	-0.273	-0.348*	-0.174	-0.054
Postprandial	-0.187	0.062	-0.267	-0.048	-0.073	-0.083
Small intestinal DP						
Preprandial	-0.173	-0.127	-0.459**	0.165	0.098	-0.220
Postprandial	-0.054	-0.149	-0.529**	0.168	0.080	0.102
Power ratio	0.165	-0.062	-0.050	0.069	0.027	0.430**

BMI: body mass index; DF: dominant frequency; DP: dominant power. *$p < 0.05$, **$p < 0.01$.

gastric and small intestinal movements using EGG and EEnG may allow consideration of nutrition and drug administration. The noninvasive measurement method may be particularly well suited for use in critically ill patients. However, there has been only one study on the use of an electrogastrogram in critically ill patients to date, and further research is warranted [30].

This study has some limitations. First, undiagnosed gastrointestinal or autonomic disorders could have affected the parameters. Regular check-ups are essential to diminish this factor. Second, since we were not able to control for emotion in this study, the parameters may have been affected if there was some emotionally stimulating event prior to the experiment [24, 31]. To address this, it may be effective to introduce an intervention such as a video that would override the emotion. However, caution should be exercised in implementing such protocols, as they involve prolonged restraint time. Third, the researchers were not blinded due to a lack of resources. The data analysts were aware that the sample comprised healthy individuals and understood the normal range of electrical activity in the gastrointestinal tract. This may have introduced analytical bias in the processing of the data. To solve such a problem, it is necessary to divide the work among the measurer, data manager, and analyst. However, no previous study has ever simultaneously measured preprandial and postprandial EGG and EEnG in as many as 50 healthy volunteers. EEnG can be measured as easily enough as EGG. This study may provide useful control data for future comparisons with patients with gastrointestinal dysmotility.

In conclusion, preprandial and postprandial EGG and EEnG measurements were performed in healthy volunteers. There was no change in the electrical activity frequency in the stomach or small intestine, but power significantly increased in both the stomach and the small intestine. Time since last meal was negatively correlated with preprandial DF, BMI was negatively correlated with DP, and stool properties were positively correlated with PR. EEnG can be measured easily and simultaneously with EGG.

Data Availability

The data used to support the findings of this study are included within Appendix VI.

Additional Points

Key Points. Electrogastrography and electroenterography are noninvasive methods of measuring the gastric and the intestinal electrical activity, respectively, but no studies have measured electrogastrography and electroenterography simultaneously. Preprandial and postprandial measurements of electrogastrography and electroenterography were taken simultaneously in healthy volunteers, and parameters were compared. There was no change in frequency in the stomach or small intestine, but power significantly increased in both the stomach and small intestine. Small intestinal contraction was negatively correlated with stool properties.

Ethical Approval

The protocol for this research project has been approved by the suitably constituted ethics committee of the institution (Ethics Committee of the University of Tsukuba Hospital, Approval No. R03-039), and it conforms to the provisions of the Declaration of Helsinki.

Consent

Informed consent was obtained from all the participants.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Authors' Contributions

GA, HS, AO, and YI were responsible for the study design. GA and MK were responsible for the data collection. GA was responsible for the statistical analysis. GA was in charge of manuscript preparation. HS, AO, MI, TH, NA, YE, NS, and YI were involved in the revision stge. All authors read and approved the final manuscript.

Acknowledgments

This work was supported by the Japan Society for the Promotion of Science KAKENHI (Grants-in-Aid for Scientific Research) [Grant Number JP22K09177].

Supplementary Materials

Appendix I: preliminary study: appropriate electrode placement for electroenterography. Appendix II: electrode placement sites and channel settings in preliminary studies. Appendix III: participants' baseline data in the preliminary study. Appendix IV: dominant frequency of the small intestine in the preliminary study. Appendix V: dominant power of the small intestine in the preliminary study. Appendix VI: minimal data. *(Supplementary Materials)*

References

[1] K. M. Sanders, S. D. Koh, S. Ro, and S. M. Ward, "Regulation of gastrointestinal motility—insights from smooth muscle biology," *Nature Reviews Gastroenterology & Hepatology*, vol. 9, no. 11, pp. 633–645, 2012.

[2] K. M. Sanders, S. M. Ward, and S. D. Koh, "Interstitial cells: regulators of smooth muscle function," *Physiological Reviews*, vol. 94, no. 3, pp. 859–907, 2014.

[3] K. M. Sanders, S. D. Koh, and S. M. Ward, "Interstitial cells of Cajal as pacemakers in the gastrointestinal tract," *Annual Review of Physiology*, vol. 68, no. 1, pp. 307–343, 2006.

[4] K. M. Sanders, Y. Kito, S. J. Hwang, and S. M. Ward, "Regulation of gastrointestinal smooth muscle function by interstitial cells," *Physiology (Bethesda, Md.)*, vol. 31, no. 5, pp. 316–326, 2016.

[5] S. Moraveji, M. Bashashati, S. Elhanafi et al., "Depleted interstitial cells of Cajal and fibrosis in the pylorus: novel features of gastroparesis," *Neurogastroenterology and Motility*, vol. 28, no. 7, pp. 1048–1054, 2016.

[6] J. J. Rumessen, "Ultrastructure of interstitial cells of Cajal at the colonic submuscular border in patients with ulcerative colitis," *Gastroenterology*, vol. 111, no. 6, pp. 1447–1455, 1996.

[7] C. Porcher, M. Baldo, M. Henry, P. Orsoni, Y. Jule, and S. M. Ward, "Deficiency of interstitial cells of Cajal in the small intestine of patients with Crohn's disease," *The American Journal of Gastroenterology*, vol. 97, no. 1, pp. 118–125, 2002.

[8] W. D. Tong, B. H. Liu, L. Y. Zhang, S. B. Zhang, and Y. Lei, "Decreased interstitial cells of Cajal in the sigmoid colon of patients with slow transit constipation," *International Journal of Colorectal Disease*, vol. 19, no. 5, pp. 467–473, 2004.

[9] M. Nakahara, K. Isozaki, S. Hirota et al., "Deficiency of KIT-positive cells in the colon of patients with diabetes mellitus," *Journal of Gastroenterology and Hepatology*, vol. 17, no. 6, pp. 666–670, 2002.

[10] J. Yin and J. D. Chen, "Electrogastrography: methodology, validation and applications," *Journal of Neurogastroenterology and Motility*, vol. 19, no. 1, pp. 5–17, 2013.

[11] J. C. Erickson, L. E. Bruce, A. Taylor et al., "Electrocolonography: non-invasive detection of colonic cyclic motor activity from multielectrode body surface recordings," *IEEE Transactions on Biomedical Engineering*, vol. 67, no. 6, pp. 1628–1637, 2020.

[12] F. Y. Chang, C. L. Lu, C. Y. Chen et al., "Fasting and postprandial small intestinal slow waves non-invasively measured in subjects with total gastrectomy," *Journal of Gastroenterology and Hepatology*, vol. 22, no. 2, pp. 247–252, 2007.

[13] J. Garcia-Casado, V. Zena-Gimenez, G. Prats-Boluda, and Y. Ye-Lin, "Enhancement of non-invasive recording of electroenterogram by means of a flexible array of concentric ring electrodes," *Annals of Biomedical Engineering*, vol. 42, no. 3, pp. 651–660, 2014.

[14] J. W. Hamilton, B. E. Bellahsene, M. Reichelderfer, J. G. Webster, and P. Bass, "Human electrogastrograms," *Digestive Diseases and Sciences*, vol. 31, no. 1, pp. 33–39, 1986.

[15] B. O. Familoni, Y. J. Kingma, and K. L. Bowes, "Noninvasive assessment of human gastric motor function," *IEEE Transactions on Biomedical Engineering*, vol. 34, no. 1, pp. 30–36, 1987.

[16] Z. Lin, I. Sarosiek, J. Forster, I. Damjanov, Q. Hou, and R. W. McCallum, "Association of the status of interstitial cells of Cajal and electrogastrogram parameters, gastric emptying and symptoms in patients with gastroparesis," *Neurogastroenterology and Motility*, vol. 22, no. 1, article e10, p. 56, 2009.

[17] D. A. Carson, S. Bhat, T. C. L. Hayes et al., "Abnormalities on electrogastrography in nausea and vomiting syndromes: a systematic review, meta-analysis, and comparison to other gastric disorders," *Digestive Diseases and Sciences*, vol. 67, no. 3, pp. 773–785, 2022.

[18] C. L. Lu, C. Y. Chen, F. Y. Chang et al., "Impaired postprandial gastric myoelectrical activity in Chinese patients with nonulcer dyspepsia," *Digestive Diseases and Sciences*, vol. 46, no. 2, pp. 242–249, 2001.

[19] J. D. Chen, B. D. Schirmer, and R. W. McCallum, "Measurement of electrical activity of the human small intestine using surface electrodes," *IEEE Transactions on Biomedical Engineering*, vol. 40, no. 6, pp. 598–602, 1993.

[20] L. J. D. O'Donnenll, J. Virjee, and K. W. Heaton, "Detection of pseudodiarrhoea by simple clinical assessment of intestinal transit rate," *BMJ*, vol. 300, no. 6722, pp. 439-440, 1990.

[21] M. R. Blake, J. M. Raker, and K. Whelan, "Validity and reliability of the Bristol Stool Form Scale in healthy adults and patients with diarrhoea-predominant irritable bowel syndrome," *Alimentary Pharmacology & Therapeutics*, vol. 44, no. 7, pp. 693–703, 2016.

[22] N. B. Popovic, N. Miljkovic, and M. B. Popovic, "Simple gastric motility assessment method with a single-channel electrogastrogram," *Biomedizinische Technik. Biomedical Engineering*, vol. 64, no. 2, pp. 177–185, 2019.

[23] G. Riezzo, F. Russo, and F. Indrio, "Electrogastrography in adults and children: the strength, pitfalls, and clinical significance of the cutaneous recording of the gastric electrical activity," *BioMed Research International*, vol. 2013, Article ID 282757, 14 pages, 2013.

[24] N. Wolpert, I. Rebollo, and C. Tallon-Baudry, "Electrogastrography for psychophysiological research: practical considerations, analysis pipeline, and normative data in a large sample," *Psychophysiology*, vol. 57, no. 9, article e13599, 2020.

[25] N. Araki, Y. Yamanaka, A. Poudel et al., "Electrogastrography for diagnosis of early-stage Parkinson's disease," *Parkinsonism & Related Disorders*, vol. 86, pp. 61–66, 2021.

[26] U. Ladabaum, S. S. Koshy, M. L. Woods, F. G. Hooper, C. Owyang, and H. Wl, "Differential symptomatic and electrogastrographic effects of distal and proximal human gastric distension," *The American Journal of Physiology*, vol. 275, no. 3, pp. G418–G424, 1998.

[27] J. Chen and R. W. McCallum, "Response of the electric activity in the human stomach to water and a solid meal," *Medical & Biological Engineering & Computing*, vol. 29, no. 4, pp. 351–357, 1991.

[28] H. P. Simonian, K. Panganamamula, H. P. Parkman et al., "Multichannel electrogastrography (EGG) in normal subjects: a multicenter study," *Digestive Diseases and Sciences*, vol. 49, no. 4, pp. 594–601, 2004.

[29] F. Y. Chang, "Electrogastrography: basic knowledge, recording, processing and its clinical applications," *Journal of Gastroenterology and Hepatology*, vol. 20, no. 4, pp. 502–516, 2005.

[30] C. Mancilla Asencio, L. R. Gálvez-Arévalo, E. Tobar Almonacid, G. Landskron-Ramos, and A. M. Madrid-Silva, "Evaluacion de motilidad gastrica mediante electrogastrografia de superficie en pacientes criticos septicos. Comparacion de los efectos de metoclopramida y domperidona: un ensayo clinico-piloto aleatorizado," *Revista de Gastroenterología de México (English Edition)*, vol. 84, no. 2, pp. 149–157, 2019.

[31] E. P. Vianna and D. Tranel, "Gastric myoelectrical activity as an index of emotional arousal," *International Journal of Psychophysiology*, vol. 61, no. 1, pp. 70–76, 2006.