Published in final edited form as:

Physiol Meas. 2014 February ; 35(2): 205–215. doi:10.1088/0967-3334/35/2/205.

Effects of body mass index on gastric slow wave: A magnetogastrographic study

S Somarajan^{1,2}, S Cassilly¹, C Obioha¹, WO Richards³, and LA Bradshaw^{1,2,4}

S Somarajan: suseela.somarajan@vanderbilt.edu

¹Department of Surgery, Vanderbilt University, Nashville, TN, USA

²Department of Physics & Astronomy, Vanderbilt University, Nashville, TN, USA

³Department of Surgery, University of South Alabama, Mobile, AL, USA

⁴Department of Physics, Lipscomb University, Nashville, TN, USA

Abstract

We measured gastric slow wave activity simultaneously with magnetogastrogram (MGG), mucosal electromyogram (EMG) and electrogastrogram (EGG) in human subjects with varying body mass index (BMI) before and after a meal. In order to investigate the effect of BMI on gastric slow wave parameters, each subject's BMI was calculated and divided into two groups: subjects with BMI ≤ 27 and BMI > 27 . Signals were processed with Fourier spectral analysis and Second-Order Blind Identification (SOBI) techniques. Our results showed that increased BMI does not affect signal characteristics such as frequency and amplitude of EMG and MGG. Comparison of the postprandial EGG power, on the other hand, showed a statistically significant reduction in subjects with BMI > 27 compared with BMI ≤ 27 . In addition to the frequency and amplitude, the use of SOBI-computed propagation maps from MGG data allowed us to visualize the propagating slow wave and compute the propagation velocity in both BMI groups. No significant change in velocity with increasing BMI or meal was observed in our study. In conclusion, multichannel MGG provides assessment of frequency, amplitude and propagation velocity of the slow wave in subjects with differing BMI categories and were observed to be independent of BMI.

Keywords

magnetogastrogram; electrogastrogram; SQUID; cutaneous electrode; mucosal electrode

1. Introduction

The slow wave is an omni-present rhythmic activity in the stomach with a frequency of about 3 cycles per minute in normal humans (Hinder and Kelly, 1977; Parkman *et al.*, 2003). Interstitial cells of Cajal (ICCs) located within the gastric musculature have been implicated as the originators and propagators of the slow wave. ICCs are electrically coupled by gap junctions to longitudinal and circular muscle layers and the electrical activity propagates passively through these layers (Thuneberg, 1982; Ordog *et al.*, 1999). Motility disorders of the stomach such as gastroparesis and functional dyspepsia are known to alter

spatiotemporal parameters of the gastric slow wave activity (Lin and Chen, 2001; Bradshaw *et al.*, 2009c; Bradshaw *et al.*, 2011). Most electromyographic (EMG) techniques for detecting gastric slow wave activity have either involved placing serosal electrodes on to the surface of the stomach during an abdominal surgery or attaching intraluminal electrodes to the mucosa of the stomach (Chen *et al.*, 1995). The difficulties in gaining access to gastrointestinal (GI) tract have limited the potential use of invasive EMG techniques for recording gastric slow wave activity. For this reason, non-invasive measurements of slow wave activity have garnered interest in clinical settings (Golzarian *et al.*, 1994; Mantides *et al.*, 1997; Zhang *et al.*, 2006).

The electrogastrogram (EGG) records the cutaneous potentials associated with gastric slow waves, but the attenuation and distortion of volume conduction reflected in the EGG complicates its use in the identification of slow wave internal sources from external measurements (Bortolotti, 1998). A recent retrospective study showed little correlation between abnormal EGG and a variety of GI disease states (Abid and Lindberg, 2007). Magnetogastrogram (MGG) also measures the same underlying electrical activity as EGG, but is not as affected by tissue conductivities as the electric potential (Bradshaw *et al.*, 2001). Previous studies in our lab have demonstrated that transabdominal MGG accurately reflects not only the frequency profile of the gastric slow wave, but also provides information about its spatiotemporal variation (Bradshaw *et al.*, 2006).

The influence of body mass index (BMI) on MGG and EGG signals is not well understood despite a handful of modeling and experimental studies that have appeared (Simonian *et al.*, 2004; Obioha *et al.*, 2013; Kim *et al.*, 2012). A previous study from our lab showed that the sensitivity of the MGG is less affected by changes in BMI than is the EGG (Obioha *et al.*, 2013). Our aim in the present study was to determine the effect of BMI on clinically significant physiological parameters associated with the gastric slow wave recorded using SQUID, cutaneous electrodes and mucosal EMG electrodes in human volunteers.

2. Materials and Methods

Twenty seven healthy human volunteers (17 men and 10 women, BMI range 18 to 55.6) participated in this study. All subjects were free of any symptoms, had no history of diabetes, gastrointestinal illness or surgery, and none was on medication known to alter gastrointestinal motor or electrical activity. A pregnancy test was performed in women volunteers prior to enrollment. Informed consent was obtained from these volunteers and the experimental procedures were approved by the Vanderbilt University Institutional Review Board.

We measured the multichannel MGG simultaneously with a sixteen channel EGG and an eight channel EMG from twenty seven healthy human volunteers, who underwent 8 hours overnight fast before the study. For the EMG study, we utilized a custom -fabricated eight channel mucosal electrode array integrated in a 4.5 mm diameter naso-gastric (NG) catheter. Electrodes were platinum rings installed concentric on the catheter, as illustrated in the Figure 1. The 4-mm long electrodes were spaced every 1.5 cm along the NG catheter. The EGG electrodes, sixteen bipolar pairs that we used were standard Beckman silver-silver

chloride sintered biopotential electrodes with a cup size of 17 mm. A multichannel SQUID magnetometer (model 637i; Tristan Technologies, CA, USA) was used to make measurements of MGG. The SQUID converts magnetic flux incident on detection coils into voltage signals. The SQUID has 19 normal component sensors in a hexagonal close packed array that measure magnetic fields perpendicular to the body surface. However, for this study, the data acquired from 17 normal-component SQUID sensors were used; two sensors were not in service due to sensor malfunction. Ten additional sensors measure tangential components of the magnetic field at locations at the top, bottom, sides and in the middle of the normal component sensor array. The other eight sensors recorded noise reference signals.

We placed the NG tube containing the eight mucosal electrodes in the pyloro-antral region along the greater curvature of the stomach. Appropriate placement of the NG tube electrode in the gastric antrum was verified by X-ray, as seen in figure 1. We positioned the bipolar nonmagnetic cutaneous electrodes on the abdomen above the stomach along the longitudinal axis. Volunteers were then placed underneath the SQUID magnetometer in a magnetically shielded room. We recorded simultaneous MGG, EMG and cutaneous EGG slow wave signals during fasting for a period of 30 minutes. The volunteers then ate a standardized 300 kcal turkey sandwich meal with a clear liquid to allow recording of the postprandial signal for a period of one hour. The subjects were asked to suspend respiration periodically to allow the comparison of noise reduction techniques.

Electrode signals were acquired at 256 Hz with the electrode amplifier (Biosemi, Amsterdam, The Netherlands) and resampled to 30 Hz. The SQUID signals were passed into a preamplifier stage with a gain of 5 and a low pass filter set of 1 KHz (Model 5000), Quantum Design, CA, USA). SQUID data were acquired at 3 KHz, and subsequently down sampled to 30 Hz. The recorded signals were transferred into MATLAB (Mathworks, Natick, MA, USA) and filtered using a second-order Butterworth filter with a bandpass of 1– 60 cycles per minute (cpm). Apart from filtering, for EGG and MGG signals, we also applied the SOBI algorithm to reduce the interfering noise signals (Belouchrani *et al.*, 1997; Erickson *et al.*, 2008; Erickson *et al.*, 2009). In our notation, SOBI-MGG and SOBI-EGG refers to the filtered signals processed using the SOBI algorithm to identify gastric signal components. All frequency spectra were computed with fast Fourier transform (FFT). Signals were classified as gastric if they were primarily sinusoidal with a dominant frequency in the gastric range (2.5–4.0 cpm).

We determined the parameters of the gastric slow wave measured by MGG, EGG and EMG including frequency and amplitude. We also computed the propagation velocities from MGG signals by computing the time of arrival of signal features in particular SQUID channels reconstructed from SOBI noise reduced data (Bradshaw *et al.*, 2011). The paired Student's t test was used for statistical comparison between signal modalities and differing BMI categories. Statistical significance was set at $p < 0.05$.

3. Results

The difficulty in achieving contact between the mucosal EMG electrodes and the gastric mucosa allowed us to detect pre and postprandial mucosal EMG consistently in only twenty subjects (14 men and 6 women, BMI range 18 to 41.3). The volunteers were selected to represent two categories: BMI ≤ 27 ($n=10$, 6 men and 4 women, average BMI = 24.3) and BMI > 27 ($n=10$, 8 men and 2 women, average BMI = 32.5). A typical set of postprandial data obtained from one of the normal BMI subjects is shown in Fig. 2. Butterworth-filtered EMG, EGG and MGG signals with their corresponding FFTs are shown in Figures 2(a-c). EGG and MGG components isolated with SOBI and their corresponding frequency spectra were illustrated in Figure 2(d-e). Normal gastric slow wave activity with a frequency of approximately 3.5 cpm is clearly evident in all recordings.

Figure 3 (a-c) illustrates the effect of BMI on gastric slow wave frequency determined from EMG, EGG, SOBI-EGG, MGG and SOBI-MGG in both pre- and postprandial recordings. A significant postprandial increase in gastric slow wave frequency was not observed in any BMI category (see table 1). Also, there were no statistically significant changes in slow wave frequency between BMI ≤ 27 and BMI > 27 subjects in EMG ($p=0.22$ pre, $p=0.79$ post), EGG ($p=0.12$ pre, $p=0.97$ post), SOBI EGG ($p=0.05$ pre, $p=0.85$ post), MGG ($p=0.30$ pre, $p=0.60$ post) or SOBI MGG ($p=0.07$ pre, $p=0.56$ post) components during pre or postprandial periods.

Figure 4 (a-c) demonstrates the effect of BMI on gastric slow wave amplitude determined from EMG, EGG and SOBI noise reduced MGG data during pre and postprandial periods. For EMG and SOBI MGG there were no differences in slow wave amplitude between BMI ≤ 27 and BMI > 27 subjects (EMG: $p=0.37$ pre, $p=0.35$ post and SOBI MGG: $p=0.30$ pre, $p=0.50$ post). EGG showed no significant difference in preprandial amplitude between BMI ≤ 27 and BMI > 27 subjects ($p=0.44$). However, there is a significant decrease in postprandial amplitude for BMI > 27 subjects compared to BMI ≤ 27 ($p<0.05$). Significant postprandial amplitude increases in EMG and SOBI-MGG for both BMI ≤ 27 and BMI > 27 subjects were also noted (see figure 4). We did not observe a significant increase in EGG amplitude following the meal in BMI > 27 subjects ($p=0.12$).

The inability to detect consistent phase shifts from electrodes in EMG and EGG hinders the computation of propagation velocity for subjects with different BMI levels. However, the use of SOBI-computed propagation maps from MGG data allowed us to visualize the propagating slow wave and compute the propagation velocity in subjects with BMI ≤ 27 and BMI > 27 . We analyzed propagation by mapping MGG - SOBI components to the SQUID array and computing phase difference from the bestfit sinusoids (Bradshaw *et al.*, 2013; Bradshaw *et al.*, 2011). Consecutive spatial maps from postprandial MGG for a typical subject is shown in figure 5. From the maps, we computed the location of the pattern maximum as a function of time to estimate the propagation velocity. The estimated velocity is the slope of the best-fit line to the pattern maximum data (Bradshaw *et al.*, 2013). In the present study, our limited spatial resolution of magnetometer allow us to observe slow wave propagation clearly in only thirteen ($n=6$; BMI ≤ 27 , $n=7$; BMI > 27) test subjects. Regardless of the BMI, SOBI-computed propagation maps reveal a left-to-right anterograde

gastric propagation in most subjects (figure 5). However, a few subjects showed right-to-left retrograde propagation during some segments of the study. The average propagation velocity during preprandial period was $8.4 \pm 0.4 \text{ mm s}^{-1}$ for BMI ≤ 27 and $8.2 \pm 0.3 \text{ mm s}^{-1}$ for BMI > 27 groups. For postprandial period, the average velocity was $8.5 \pm 0.6 \text{ mm s}^{-1}$ for BMI ≤ 27 and $8.2 \pm 0.4 \text{ mm s}^{-1}$ for BMI > 27 groups. These values are consistent with the known velocity of propagation of the gastric slow wave (Bradshaw *et al.*, 2011). No significant change in velocity with increasing BMI or meal was observed.

4. Discussion and conclusion

Our group and others have previously reported the ability of EGG and MGG to detect slow wave parameters, in particular amplitude, frequency and propagation velocity (Chen *et al.*, 1999; Bradshaw *et al.*, 2006). Several studies have shown that the cutaneous EGG contains frequencies similar to those recorded by internal serosal electrodes (Smout *et al.*, 1980; Hamilton *et al.*, 1986), but other EGG variables, including amplitude and propagation velocity, do not correlate as well (Familoni, 1994). Also, in obese volunteers slow wave propagation was not identified using EGG (Chen *et al.*, 1989). Previous studies by several researchers have demonstrated that MGG overcomes many of the limitations of EGG (Allescher *et al.*, 1998; Buist *et al.*, 2004; Estombelo-Montesco *et al.*, 2007). Since magnetic fields are mediated by permeability instead of conductivity, and since the permeabilities of fat and other tissues are nearly equal to that of free space, conductivity effects on the MGG are minimal (Bradshaw *et al.*, 2001). Realistic torso models by Kim *et al.* showed that magnetic fields preserved the information of gastric electrical activity better than potential fields in the change of fat thickness or conductivity (Kim *et al.*, 2012). In addition to the ability to detect gastric slow wave signals with less abdominal volume conductor effect, MGG can detect characteristics of slow wave propagation (Bradshaw *et al.*, 2006), identify uncoupling of the electrical syncytium (Bradshaw *et al.*, 2009b) and distinguish spiking activity (Irimia *et al.*, 2006).

Although research effort has been focused on determining the impact of anthropometric parameters on gastric slow wave activity using bioelectric technique, a systematic characterization based on noninvasive biomagnetic method has not been previously reported. Riezzo *et al.* previously reported the effect of obesity on gastric electrical activity using EGG. Comparison of the mean frequency values of gastric spectral peak did not reveal statistically significant differences among non-obese and their age matched obese counterparts (Riezzo *et al.*, 1991). Since the application of SOBI algorithm improved both MGG and EGG (Somarajan *et al.*, 2012), in the present study, other than EMG, EGG and MGG, we also employed SOBI-EGG and SOBI-MGG for dominant frequency calculation. Our data showed that increases in BMI do not have any influence on dominant frequencies determined using these modalities. Also, insignificant postprandial changes in slow wave frequency were observed for BMI ≤ 27 and BMI > 27 groups.

Our results showed that increased BMI does not affect the signal amplitudes of EMG and MGG. However, postprandial EGG power was lower in BMI > 27 groups than BMI ≤ 27 in our study. We believe this to be due to an increased distance from the stomach to the abdominal wall. A similar result was reported by Simonian *et al.* (Simonian *et al.*, 2004) in a

multicenter study, where they observed a decrease in the absolute amplitude of the EGG signal in subjects with BMI > 25 as compared to those with BMI < 25. We also noted an insignificant increase in EGG amplitude following the meal in BMI > 27 subjects, obscured apparently because of the increased BMI.

Propagation velocity is an important parameter of gastric electrical activity and is not reliably measured with bioelectric measurements. Our group has been able to reliably identify propagation and compute propagation velocity from MGG in human subjects using surface current density mapping (Bradshaw *et al.*, 2009a). Recently, Bradshaw et al reported SOBI-computed propagation maps from MGG data for the calculation of propagation velocity of gastric magnetic fields. A left-to-right anterograde gastric propagation with an average propagation velocity of $8.3 \pm 0.6 \text{ mm s}^{-1}$ was observed in healthy human subjects (Bradshaw *et al.*, 2011). In the present study, regardless of the BMI, spatiotemporal examination of SOBI-computed propagation maps reveals a left-to-right anterograde gastric propagation in most subjects. Pattern characteristics like abnormal rotations without definite propagation patterns were not observed in any of this study population. However, a few subjects showed right-to-left propagation pattern that typically indicate retrograde propagation during some segments of the study. This suggests that the ability to detect left-to-right anterograde propagation pattern in normal subjects may be somewhat variable. In the normal human stomach, slow waves originate near the proximal greater curvature of the corpus and propagate toward the pylorus at a frequency of approximately three cycles per minute (O'Grady *et al.*, 2010). The stomach, however, is a hollow organ with variable shape and size. It is also a mobile organ that has the potential to rotate along its long axis. Its mobility accounts for subtle changes in the shape and position of the stomach with change in posture or ingestion of food. We believe that these reasons may have accounted for the changes in propagation patterns that are observed in some of the volunteers in this study. However, future studies are needed to help us better understand the propagation patterns in healthy humans by comparing imaging studies with their SOBI-computed propagation maps.

In conclusion, this study investigated the influence of BMI on gastric slow wave parameters using a non-invasive biomagnetic technique, and our results showed that increased BMI does not affect signal characteristics such as frequency, amplitude and propagation velocity of MGG. Non-invasive MGG is highly correlated with potentials recorded by invasive mucosal electrodes in both BMI groups. In BMI > 27 subjects, there are discrepancies in the amplitude of EGG compared with EMG and MGG, which may be due to the low-conductivity fat layers in the abdomen of obese subjects. The ability of MGG to noninvasively characterize slow wave parameters such as frequency, amplitude and propagation velocity in subjects with high BMI could have significant impact in clinical settings.

Acknowledgments

This work is supported in part by NIH grants R01 DK58697 and R01 DK58197. The authors greatly acknowledge the work of Dr. Jon Erickson who developed the SOBI algorithm for the analysis of gastrointestinal slow wave activity. We thank the staff of SR Light laboratories at Vanderbilt University Medical Center for their assistance in this study. The authors would also like to thank Ms. Nicole Muszynski for editorial assistance.

References

- Abid S, Lindberg G. Electrogastrography: Poor correlation with antro-duodenal manometry and doubtful clinical usefulness in adults. *World Journal of Gastroenterology*. 2007; 13:5101–5107. [PubMed: 17876876]
- Allescher HD, Abraham-Fuchs K, Dunkel RE, Classen M. Biomagnetic 3-dimensional spatial and temporal characterization of electrical activity of human stomach. *Digestive Diseases and Sciences*. 1998; 43:683–693. [PubMed: 9558020]
- Belouchrani A, AbedMeraim K, Cardoso JF, Moulines E. A blind source separation technique using second-order statistics. *Ieee Transactions on Signal Processing*. 1997; 45:434–444.
- Bortolotti M. Electrogastrography: A seductive promise, only partially kept. *American Journal of Gastroenterology*. 1998; 93:1791–1794. [PubMed: 9772032]
- Bradshaw LA, Cheng LK, Richards WO, Pullan AJ. Surface Current Density Mapping for Identification of Gastric Slow Wave Propagation. *Ieee Transactions on Biomedical Engineering*. 2009a; 56:2131–2139. [PubMed: 19403355]
- Bradshaw LA, Erickson JR, Chung E, Richards WO. Gastroparesis alters magnetogastrogram propagation patterns. *Neurogastroent Motil*. 2011; 23:7.
- Bradshaw LA, Irimia A, Sims JA, Gallucci MR, Palmer RL, Richards WO. Biomagnetic characterization of spatiotemporal parameters of the gastric slow wave. *Neurogastroent Motil*. 2006; 18:619–631.
- Bradshaw LA, Irimia A, Sims JA, Richards WO. Biomagnetic signatures of uncoupled gastric musculature. *Neurogastroent Motil*. 2009b; 21:778. E50.
- Bradshaw LA, Kim J, Cassilly S, Somarajan S, Richards WO, Cheng LK. Analysis of propagation in the magnetogastrogram from multichannel biomagnetic recordings. Manuscript in preparation. 2013
- Bradshaw LA, Obioha CB, Chung E, Erickson J, Richards WO. Biomagnetic Signatures of Diabetic Gastroparesis. *Gastroenterology*. 2009c; 136:A785-A.
- Bradshaw LA, Richards WO, Wikswo JP. Volume conductor effects on the spatial resolution of magnetic fields and electric potentials from gastrointestinal electrical activity. *Medical & Biological Engineering & Computing*. 2001; 39:35–43. [PubMed: 11214271]
- Buist ML, Cheng LK, Yassi R, Bradshaw LA, Richards WO, Pullan AJ. An anatomical model of the gastric system for producing bioelectric and biomagnetic fields. *Physiological Measurement*. 2004; 25:849–861. [PubMed: 15382826]
- Chen J, Vandewalle J, Sansen W, Vancutsem E, Vantrappen G, Janssens J. Observation of the Propagation Direction of Human Electrogastroic Activity from Cutaneous Recordings. *Medical & Biological Engineering & Computing*. 1989; 27:538–542. [PubMed: 2622237]
- Chen JDZ, Pan J, McCallum RW. Clinical-Significance of Gastric Myoelectrical Dysrhythmias. *Digestive Diseases*. 1995; 13:275–290. [PubMed: 8542663]
- Chen JDZ, Zou XP, Lin XM, Ouyang S, Liang J. Detection of gastric slow wave propagation from the cutaneous electrogastrogram. *Am J Physiol-Gastr L*. 1999; 277:G424–G30.
- Erickson J, Obioha C, Goodale A, Bradshaw A, Richards W. Noninvasive detection of small bowel electrical activity from SQUID magnetometer measurements using SOBI. *Conf Proc IEEE Eng Med Biol Soc*. 2008; 2008:1871–1874. [PubMed: 19163053]
- Erickson JC, Obioha C, Goodale A, Bradshaw LA, Richards WO. Detection of Small Bowel Slow-Wave Frequencies From Noninvasive Biomagnetic Measurements. *Ieee Transactions on Biomedical Engineering*. 2009; 56:2181–2189. [PubMed: 19497806]
- Estombelo-Montesco CA, de Araujo DB, Silva ACR, Moraes ER, Barros AK, Wakai RT, Baffa O. Dependent component analysis for the magnetogastrographic detection of human electrical response activity. *Physiological Measurement*. 2007; 28:1029–1044. [PubMed: 17827651]
- Familoni, B. Validity of the cutaneous electrogastrogram. New York: Raven Press; 1994.
- Golzarian J, Staton DJ, Wikswo JP, Friedman RN, Richards WO. Diagnosing Intestinal Ischemia Using a Noncontact Superconducting Quantum Interference Device. *American Journal of Surgery*. 1994; 167:586–592. [PubMed: 8209933]

- Hamilton JW, Bellahsene BE, Reichelderfer M, Webster JG, Bass P. Human Electrogastrograms - Comparison of Surface and Mucosal Recordings. *Digestive Diseases and Sciences*. 1986; 31:33–39. [PubMed: 2934238]
- Hinder RA, Kelly KA. Human Gastric Pacesetter Potential - Site of Origin, Spread, and Response to Gastric Transection and Proximal Gastric Vagotomy. *American Journal of Surgery*. 1977; 133:29–33. [PubMed: 835775]
- Irimia A, Richards WO, Bradshaw LA. Magnetogastrographic detection of gastric electrical response activity in humans. *Physics in Medicine and Biology*. 2006; 51:1347–1360. [PubMed: 16481699]
- Kim JHK, Pullan AJ, Bradshaw LA, Cheng LK. Influence of body parameters on gastric bioelectric and biomagnetic fields in a realistic volume conductor. *Physiological Measurement*. 2012; 33:545–556. [PubMed: 22415019]
- Lin XM, Chen JDZ. Abnormal gastric slow waves in patients with functional dyspepsia assessed by multichannel electrogastrography. *Am J Physiol-Gastr L*. 2001; 280:G1370–G1375.
- Mantides A, Stefanides G, Kioulanis J, Tzovaras G, Epanomeritakis E, Xynos E. Cutaneous electrogastrography for the assessment of gastric myoelectrical activity in type I diabetes mellitus. *American Journal of Gastroenterology*. 1997; 92:1190–1193. [PubMed: 9219797]
- O'Grady G, Du P, Cheng LK, Egbuji JU, Lammers WJEP, Windsor JA, Pullan AJ. Origin and propagation of human gastric slow-wave activity defined by high-resolution mapping. *Am J Physiol-Gastr L*. 2010; 299:G585–G592.
- Obioha C, Erickson J, Somarajan S, Hajri T, Chung E, Richards WO, Bradshaw LA. Effect of Body Mass Index on the sensitivity of Magnetogastrogram and Electrogastrogram. *Journal of Gastroenterology and Hepatology Research*. 2013; 2:513–519.
- Ordog T, Ward SM, Sanders KM. Interstitial cells of Cajal generate electrical slow waves in the murine stomach. *Journal of Physiology-London*. 1999; 518:257–269.
- Parkman HP, Hasler WL, Barnett JL, Eaker EY. Electrogastrography: a document prepared by the gastric section of the American Motility Society Clinical GI Motility Testing Task Force. *Neurogastroent Motil*. 2003; 15:89–102.
- Riezzo G, Pezzolla F, Giorgio I. Effects of Age and Obesity on Fasting Gastric Electrical-Activity in Man - a Cutaneous Electrogastrographic Study. *Digestion*. 1991; 50:176–181. [PubMed: 1812043]
- Simonian HP, Panganamamula K, Parkman HP, Xu XH, Chen JDZ, Lindberg G, Xu H, Shao C, Ke MY, Lykke M, Hansen P, Barner B, Buhl H. Multichannel electrogastrography (EGG) in normal subjects: A multicenter study. *Digestive Diseases and Sciences*. 2004; 49:594–601. [PubMed: 15185863]
- Smout AJPM, Vanderschee EJ, Grashuis JL. What Is Measured in Electrogastrography. *Digestive Diseases and Sciences*. 1980; 25:179–187. [PubMed: 7371462]
- Somarajan S, Muszynski ND, Obioha C, Richards WO, Bradshaw LA. Biomagnetic and bioelectric detection of gastric slow wave activity in normal human subjects-a correlation study. *Physiological Measurement*. 2012; 33:1171–1179. [PubMed: 22735166]
- Thunberg L. Interstitial-Cells of Cajal - Intestinal Pacemaker Cells. *Advances in Anatomy Embryology and Cell Biology*. 1982; 71:1–130.
- Zhang HH, Xu XH, Wang ZF, Li CX, Ke MY. Correlation between gastric myoelectrical activity recorded by multi-channel electrogastrography and gastric emptying in patients with functional dyspepsia. *Scandinavian Journal of Gastroenterology*. 2006; 41:797–804. [PubMed: 16785192]

Figure 1.

X-ray showing the placement of NG tube in the subject's stomach

Figure 2.

(a)–(c) Butterworth filtered EMG, EGG and MGG signals (upper row) and their corresponding frequency spectra (lower row) during the postprandial period. (d) - (e) EGG and MGG components isolated with SOBI (upper row) and their corresponding frequency spectra (lower row).

Figure 3.

(a-c) Effect of BMI on gastric slow wave frequency determined from EMG, EGG, SOBI EGG, MGG and SOBI MGG. The slow wave frequencies were observed to be independent of the BMI. The gastric slow wave frequency did not exhibit a significant postprandial increase in any BMI weight status categories.

Figure 4.

Effect of BMI on gastric slow wave amplitude determined from (a) EMG (b) EGG and (c) SOBI-MGG data during pre and postprandial periods. Significant postprandial amplitude increases were denoted by *.

Figure 5.
SOBI-computed propagation maps from postprandial MGG for a typical subject.

Table 1

Slow wave frequencies in differing BMI categories measured using EMG, EGG, SOBI EGG, MGG and SOBI MGG.

	BMI 27 Frequency (cpm)		BMI > 27 Frequency (cpm)	
	Pre	Post	Pre	Post
EMG	2.89 ± 0.05	3.01 ± 0.09, <i>p</i> = 0.09	2.97 ± 0.04	2.98 ± 0.05, <i>p</i> = 0.78
EGG	2.9 ± 0.06	2.99 ± 0.09, <i>p</i> = 0.26	2.98 ± 0.04	2.98 ± 0.05, <i>p</i> = 0.90
SOBI EGG	2.93 ± 0.06	3.01 ± 0.08, <i>p</i> = 0.21	3.02 ± 0.04	3.03 ± 0.06, <i>p</i> = 0.86
MGG	2.89 ± 0.07	3.03 ± 0.1, <i>p</i> = 0.17	2.97 ± 0.05	2.98 ± 0.05, <i>p</i> = 0.96
SOBI MGG	2.91 ± 0.05	3.04 ± 0.09, <i>p</i> = 0.15	2.99 ± 0.03	2.98 ± 0.04, <i>p</i> = 0.86

p values between pre/postprandial frequencies are also shown.