NONINVASIVE MEASUREMENT OF GASTRIC PROPAGATION USING A SQUID MAGNETOMETER

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Abstract

A vector Superconducting QUantum Interference Device (SQUID) magnetometer was used to measure the magnetic fields associated with propagation of gastric electrical activity. Measurements of the magnetic field vector were consistent with the presumed pattern of current propagation in the gastric musculature. Further studies using two SQUID systems allowed the first noninvasive determination of the gastric propagation velocity.

Introduction

The gastrointestinal (GI) system is responsible for the processing of dietary nutrients and the removal of waste products. The Basic Electrical Rhythm (BER), or slow wave, is an omnipresent oscillatory activity that originates in GI smooth muscle. The gastric slow wave activity oscillates with a frequency of about 3 cycles per minute (cpm) and propagates from the location of the pacemaker along the greater curve of the antrum toward the pylorus.

Noninvasive detection of GI electrical activity interests clinicians. Cutaneous electrodes used in electrogastrography (EGG) have been limited to measurements of frequency dynamics of the gastric activity -- amplitude data is not reliable due to the possibility of gastric distension-- and have not been reliable in detecting intestinal activity (3). Prior model simulations showed that the filtering effect of the low-conductivity abdominal layers serves to drastically reduce the electric potentials (1).

Magnetic fields are not as affected by conductivities, as they are mediated by the relatively constant magnetic permeability of tissues. Our previous studies have shown that SQUID magnetometers may be used to measure noninvasively gastrointestinal electrical activity (5). Those studies showed that SQUIDs detected the 3 cycle per minute (cpm) slow wave associated with gastric electrical activity as well as the variable 8 to 12 cpm intestinal activity. Furthermore, the expected BER frequency gradient of the intestine has been observed in magnetic measurements at multiple recording locations around the abdomen.

Propagation of the gastric electrical activity has been observed with invasive electrodes, but has not been detected noninvasively. A single gastric wave propagates from the pacemaker site in the antrum to the pylorus with roughly the same frequency as the gastric BER. Publicover and Sanders (4) determined that gastric propagation velocity to be 0.3 ± 0.1 cm/s in muscles of the gastric corpus and 0.65 ± 0.2 cm/s in antral muscles. One study using cutaneous electrodes was able to determine the direction of propagation from cutaneous measurements, but could not reliably determine the propagation

velocity (2). The purpose of the present study is to investigate the capabilities of the SQUID magnetometer in noninvasive measurements of gastric propagation.

Methods

Ten normal volunteers were studied under nonmagnetic conditions. The subjects were positioned under a three-channel SQUID magnetometer that recorded the magnetic field at a single recording site, and recordings were obtained in 3 locations in the epigastrium along the midline, and 5 cm to the left and right of midline. The three SQUID detection coils are arranged in three orthogonal planes to measure all three components of the gastric and intestinal magnetic fields. Data were collected with a sampling rate of 30 Hz and a bandwidth between 0.01-10 Hz. Subjects were asked to suspend respiration during data collection to avoid distortion of the magnetic signal by respiratory artifact. Power spectral estimates were obtained using an autoregressive power spectral density (AR PSD) estimate.

The vector magnetic field was decomposed into 32 projections around a unit sphere according to:

$$B_i = \hat{i}B_x \sin\theta_i \cos\phi_i + \hat{j}B_y \sin\theta_i \sin\phi_i + \hat{k}B_z \cos\theta_i, \quad (1)$$

for $i = 1, ..., 32$; ϕ_i and θ_i chosen to give 32 regular projections around a unit sphere (6). Particular vector projections corresponding to maximal gastric and or small bowel signal components were identified by determining the projection with maximal signal in the 2.5-4 cpm gastric frequency range.

Because the vector SQUID used for these studies recorded the vector field at only one location, it could not be used alone to measure the gastric propagation velocity. To obtain an estimate of gastric propagation velocity noninvasively, we used another SQUID magnetometer as a reference magnetometer to correlate gastric waves with those recorded in three locations along the longitudinal axis of the stomach with the vector SQUID. The reference SQUID magnetometer was not designed for biomagnetic studies, but we found that it displayed a signal-to-noise ratio that was adequate to detect the gastric activity. A cross-correlation analysis of simultaneous recordings from the reference SQUID and the vector SQUID at each of the three positions determined the phase delay in the successive vector SQUID positions in a manner similar to that described in Chen et al. (2). The propagation velocity was then estimated by

$$v_{prop} = \frac{\text{Mag. Spacing} \times \text{BER Frequency}}{\text{Phase Delay}} \quad (2)$$

Results

Data obtained from the three epigastric sections of one subject

and their AR power spectra are shown in Fig. 1. The gastric activity is most pronounced in the central section where the SQUID is closest to the stomach. In all subjects the average recorded gastric frequency was 3.03±0.18 cpm (mean ± SEM).

The gastric vector projection from the same subject is shown in Fig. 2. The gastric vector is oriented in the superior direction toward the subject's head. Overall, the gastric vector was oriented at 96.0 ± 33.7° from the axis transverse to the abdomen, consistent with propagation of current along the longitudinal axis of the stomach. Magnetic field vectors not associated with gastric activity display random orientations. Whereas the variation of gastric vector orientation was 33.7°, the variation of non-gastric vector orientation is 129.3°.

The cross-correlation analysis from the dual SQUID measurements revealed a mean propagation velocity of 0.38±0.10 cm/s in the corpus and 0.41±0.09 cm/s in the antrum. These results are consistent with the earlier invasive electrode measurements.

Discussion

The noninvasive detection of gastric electrical activity and its propagation patterns is of tremendous clinical importance. Several pathologic conditions may be related to abnormal gastric propagation. For instance, gastroparesis, a condition common among diabetics, may display diminished or retrograde propagation patterns.

This report represents the first magnetic detection of gastric propagation direction and the first noninvasive measurements of gastric propagation velocity. The magnetic field vector associated with gastric activity was oriented superiorly, toward the subject's head. Since magnetic fields tend to wrap around propagating current patterns, this orientation of the magnetic field vector is expected to be perpendicular to the direction of current propagation. Thus, the superiorly directed magnetic field vector is consistent with current propagation along the axis of the stomach.

The gastric propagation velocity determined by the dual SQUID measurements was consistent with previous data from serosal electrodes (4). The cross-correlation analysis technique provided for simple identification of the phase delay between successive positions of the vector magnetometer.

Although these studies were quite successful, there were several factors that decreased the signal quality. The reference magnetometer was not designed for biomagnetic studies, and as such the signal-to-noise ratio was not adequate for gastric measurements. The data we collected would be improved with a multichannel vector magnetometer. Using such an instrument, one should be able to noninvasively measure the gastric magnetic field vector in each channel and use multiple channels to determine the gastric propagation velocity noninvasively. Future studies will investigate the utility of a multichannel magnetometer to detect gastrointestinal activity.

References

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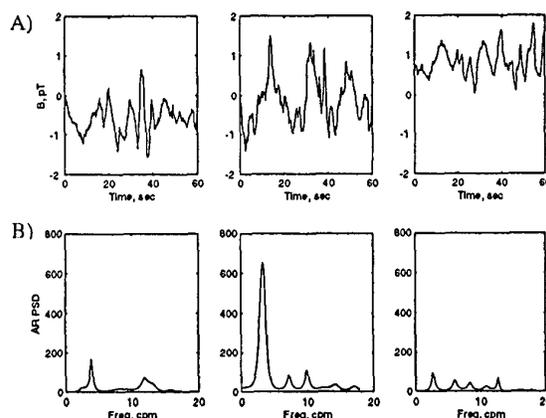
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Fig. 1. Magnetic fields (A) and power spectra (B) measured from three upper abdominal sections showing gastrointestinal activity. The gastric signal is most dominant in the middle section near the stomach.
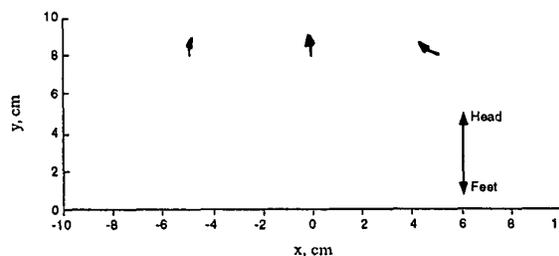

Fig. 2. The average magnetic field vectors from gastric BER is largest in the middle section nearest the stomach. The cephalic orientation of the gastric vector suggests current propagation in the perpendicular direction, roughly along the stomach axis.