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IN VIVO DETECTION OF NORMAL AND PATHOLOGIC BOWEL ELECTRICAL ACTIVITY USING A SQUID MAGNETOMETER

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Abstract
The Superconducting QUantum Interference Device (SQUID) magnetometer can non-invasively detect the magnetic fields created by the Basic Electrical Rhythm (BER) of the Gastrointestinal Tract (GIT). Using anesthetized adult male New Zealand rabbits we recorded signals from two isolated bowel segments at the same time, before and after ischemia was induced in either one or both bowel segments. The dominant frequency peaks for each period of recording were determined using autoregressive (AR) spectral analysis. There was a significant fall in the BER frequency in the ischemic segment from 11.8±0.9 to 7.8±0.6 cycles per minute (cpm), while there was no change in the normal bowel. It was possible for two observers (LAB, WOR) who were blinded to the preparation, to identify which bowel segment was ischemic. The results of this experiment demonstrate the ability of the SQUID magnetometer to non-invasively detect and differentiate signals from normal and ischemic bowel sources.

Introduction
The Gastrointestinal Tract (GIT) possesses an omnipresent slow wave activity (called the Basic Electrical Rhythm, BER), and a higher-frequency spiking activity representing peristaltic activity. The BER is constant for any given part of the GIT. Gastric BER typically has an oscillation frequency of 3 cpm, while in the small intestine there is a frequency gradient which decreases in a stepwise manner from 12 cpm in the duodenum to 8 cpm in the distal ileum. Biomagnetic fields are associated with this electric activity of the stomach and intestine.
Gastrointestinal electrical activity was first recorded in 1922 by Alvarez, using electrodes attached to the tissue surface. The magnetic fields generated by this electrical activity can be measured using a SQUID magnetometer. We have previously measured the BER frequency of the rabbit small intestine, and have also detected the BER changes that occur when short-term (30 minute) ischemia and subsequent reperfusion were induced in an isolated segment of small bowel.(Richards et al. 1995). In these studies we were able to demonstrate that non-invasive magnetic field measurements correlated very well with invasive serosal electrode measurements.
The purpose of the current study was to detect and measure, in vivo, the magnetic field signals from two different isolated sources, either one or both of which were made ischemic for prolonged periods (120 minutes), and investigate whether it was possible to differentiate normal from ischemic bowel signals.

Methods
Ten adult male New Zealand rabbits were kept on non-magnetic diet for 3 days, and were studied under general anesthesia (Acepromazine/Xylazine/Ketamine) after an overnight fast. They were placed on a water-perfused heating pad to maintain their body temperature, and intravenous normal saline was administered to maintain hydration status.
Each rabbit was secured onto a wooden platform (animal set-up). After a mid-line laparotomy, a 50 cm segment of jejuno-ileum was identified with its vascular supply. This segment of bowel was sutured to the anterior abdominal wall on one side (left or right). A colectomy was done on that side, so that signals were recorded from only that segment of bowel. Another segment of small bowel was sutured to the abdominal wall on the other side. A strip of gauze was placed in the midline to separate bowel loops in the left abdomen from loops on the right. The sutures were used as markers on the exterior of the abdominal wall to indicate the internal position of the selected bowel segments. The animal set-up was placed under the SQUID in a magnetic shield. The wooden platform was placed in a marked position (to maintain constancy of position) on a movable X-Y stage whose coordinates could be determined and altered as necessary via a joystick remote control system. Coordinates were determined for the Right and Left Lower Quadrants of the abdomen (RLQ and LLQ) where signals were best detected. Baseline recordings were taken in both RLQ and LLQ.
The animal set-up was taken out of the magnetic shield. Ischemia of the chosen bowel segment was

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induced by silk suture ligation of its vascular supply. The animal set-up was then re-positioned on the X-Y stage. Alternate 2 minute recordings were taken from RLQ and LLQ for a duration of 120 minutes. The animal set-up was then taken out of the magnetic shield.

The data acquisition system consisted of a one-channel SQUID housed in helium-filled dewar placed in a magnetic shield. This was connected to a multiplexor and then to a differential amplifier with a bandwidth setting between 0.01-1.0 Hz. Data was acquired at a sampling rate of 20 Hz on a personal computer (Macintosh Quadra 800, Apple Computer, Cupertino, CA) running LabVIEW (National Instruments, Austin, TX).

Power spectral analysis was done using the autoregressive (AR) method. The AR spectral analysis was preferred over Fast Fourier Transformation (FFT) because it permitted analysis of the short recording duration of 2 minutes.

Results

The SQUID was able to record the BER frequency in both bowel segments throughout the experiment. The average BER frequency for normal bowel was 11.8±0.9 cpm. The average BER frequency for ischemic bowel after 120 minutes of ischemia was 7.8±0.6 cpm; this was significantly different from normal ($p<.001$). We analysed the frequency and could determine which recordings were normal bowel and which were ischemic .

Discussion

These results have shown that the SQUID can non-invasively detect the BER frequency in normal bowel as well as the changes that occur when acute mesenteric ischemia is induced. We have recorded a significant decrease in the BER from 11.8±0.9 to 7.8±0.6 cycles per minute (cpm). Moreover, it is evident that the signals that emanate from different segments of bowel can be detected and measured, thereby making it feasible for differentiation of dipole sources from normal and ischemic bowel in the same abdomen during the same time period.

These measurements have been done on isolated segments of bowel using a single channel SQUID. It was possible to scan only one section of the abdomen at a time, so that the bowel segments were scanned during alternate 2 minute periods over a 120 minute time frame. Therefore, in order to have strictly simultaneous and concurrent measurements a multi-channel device will be needed. Further studies will evaluate the use of SQUIDs to detect signals emanating from free-lying bowel in the abdominal cavity and to solve the inverse problem. This would be a step nearer the realization of the objective of clinical application of the SQUID magnetometer in evaluating GIT pathophysiology.

References

[1] Richards WO et al. "Noninvasive Diagnosis of Mesenteric Ischemia Using a SQUID Magnetometer." Annals of Surgery **221** (6):696-705, 1995