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MAGNETIC VECTOR ANALYSIS OF GASTROINTESTINAL ELECTRICAL CONTROL ACTIVITY

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Abstract-**The electrical control activity (ECA) of the gastrointestinal tract exists as an omnipresent slow wave that characterizes the underlying activity of the smooth muscle. In the presence of mesenteric ischemia, small intestine ECA in animal models decreases over time. One-dimensional, multichannel SQUID magnetometers can nonivasivley record magnetic fields associated with ECA activity. Using vector optimization, we can resolve three orthogonal channels into a single vector corresponding to a single loop of normal or ischemic small intestine. We recorded the magnetic fields associated with the ECA of three male pigs after induction of ischemia using optimized vectors to discern the activity of the affected loop of bowel. A Student's T-test was performed to determine if the change in ECA frequency after induction of ischemia was significant.**

I. INTRODUCTION

The electrical control activity (ECA) of the gastrointestinal tract exists as an omnipresent slow wave that characterizes the underlying activity of smooth muscle. Action potentials, which occur only during sufficient ECA depolarization, cause contraction of the smooth muscle. Because of this activity, the ECA is present even in the absence of smooth muscle contraction and peristalsis [1]. In animal models, this electrical activity typically originates in the stomach with a frequency of 4 cycles per minutes (cpm) and propagates distally towards the duodenum (12 cpm) and terminal ileum (6 cpm).

Mesenteric ischemia, characterized by a lack of arterial blood flow to the small intestine, produces a pronounced slowing of the normal ECA [1]. Previous studies show that extracellular electric and magnetic fields may be measured from the underlying ECA. We also previously showed that one-dimensional, noninvasive recordings of gastrointestinal magnetic fields using a Superconducting QUantum Interference Device (SQUID) magnetometer correlate with ECA recordings from internal serosal electrodes. During episodes of ischemia, the SQUID can record the expected decrease in ECA frequency.

Our aim in this work was to resolve magnetic recordings from three orthogonal directions into one magnetic vector corresponding to a single loop of ischemic intestine and use these vector resolutions to track changes in intestinal ECA during episodes of induced ischemia.

II. METHODOLOGY

We anesthetized three male pigs weighing approximately 50 lbs each with isoflurane anesthetic. We performed a laparotomy, and a 30 cm section of proximal jejunum was isolated and sutured to the abdominal wall. The mesenteric blood supply to this section of jejunum was then isolated using umbilical tape and the laparotomy closed. We then placed the pig in close proximity to a 37 channel SQUID magnetometer with 19 normal component detectors and ten tangential component detectors (5 x detectors, 5 y detectors). Continuous recordings were taken for 15 minutes prior to ligation of the mesenteric blood supply. The mesenteric blood supply was then ligated, inducing ischemia, and the pig was again placed in close proximity to the SQUID magnetometer. Measurements were then taken for 45 minutes. Breath holds were given during baseline and during ischemia to remove motion artifact.

At the completion of the study, three orthogonal channels located over the intestine were resolved into multiple vectors at a single time point during the study. Using autoregressive (AR) spectral analysis, we analyzed each magnetic vector for the recorded frequencies. Using an optimization function, we attempted to pick a vector that would increase the overall representation of the desired frequency (ischemic or normal) while reducing the presence of unwanted frequencies (stomach, ileum, etc.). We used the optimum vector tracings to follow the activity of the ischemic and normal loops of bowel for the duration of the study. Equation (1) represents the calculated vector ($B_{intestine}$) with a_x, a_y, and a_z chosen to optimize the desired ECA frequency and reduce and biological or environmental noise.

$$B_{intestine} = a_x B_x + a_y B_y + a_z B_z \qquad (1)$$

After tracing the vectors over the course of the study, a Student's t-test was used to identify any significant difference between the normal and ischemic intestine.

III. RESULTS

An example of three orthogonal channels and their resulting optimized vectors simultaneously recording ischemic and normal intestine is shown in Fig. 1.

Over the course of one minute, channels in the x-direction, the y-direction, and the z-direction recorded both normal and ischemic sections of bowel. Using vector optimization, the resulting normal vector shows a strong, normal frequency of 12.5 cpm in the AR and the resulting ischemic vector shows a strong, ischemic signal at 5.2 cpm. Although evident in the original recordings, the vector analysis provides a more accurate representation of the specific ECAs of the different loops of bowel. Over the course of the study, we did notice a change in direction of the ischemic vector prompting us to re-define the vector at each time point.

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Using these optimized vectors to record the unique activity of the individual loops of bowel, we found the mean ECA frequencies of normal bowel to be 11.24 ± .26 cpm and those of ischemic bowel to be 6.08 ± .34 cpm over the course of the study. As shown in Fig 2., during the study, normal intestine maintains a constant ECA near its initial value while ischemic intestine show a decrease in ECA characteristic of mesenteric ischemia.

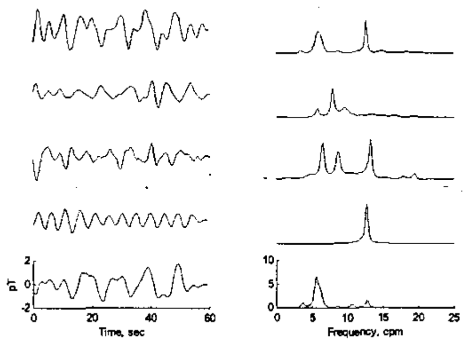

Fig. 1. Magnetic field and AR analysis recorded in three orthogonal directions (plots 1,2,3) with frequency components in both the ischemic and normal range 30 minutes after induction of ischemia. The two optimized vectors (plots 4,5) indicate the normal signal (12.5 cpm) and the ischemic signal (5.2 cpm).

A Student's t-test showed statistical significance (p<.0001) when comparing the ECA frequencies of the ischemic and normal vectors over the course of the study after mesenteric ligation. Using vector tracings like those found in Fig. 1, we were able to record the actual ECA of the intestine and discern its activity over the course of the study.

IV. Discussion/Conclusions

We have shown a novel approach to obtaining magnetic vector recordings using three orthogonal channels on a multi-channel SQUID. These new vector projections provide data that is more representative of the actual tissue we are observing by reducing noise contributed by other biological and environmental factors. This new analysis technique, along with the obtained results in our animal studies, suggests that the SQUID magnetometer represents an improved modality for noninvasive detection of mesenteric ischemia.

Acknowledgement

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References

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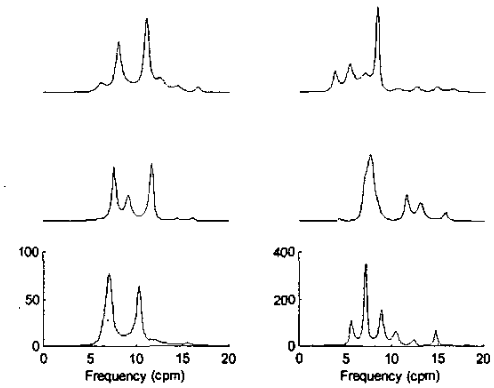

Fig. 2. Optimized normal vectors (left) and optimized ischemic vectors (right) at 10 minutes, 20 minutes, and 30 minutes after induction of ischemia. Normal signal begins at 11.5 cpm and ends at 10.5 cpm. Ischemic signal begins at 9 cpm, passes through 7.5 cpm and ends at 6 cpm.