MAGNETOENTEROGRAPHY FOR DETECTION OF INTESTINAL ISCHEMIA IN RABBITS
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Abstract

Human intestinal ischemia is a potentially fatal medical emergency that does not currently have a reliable noninvasive method of diagnosis. Previous animal studies using serosal electrodes have shown that ischemic small bowel has a lower basic electrical rhythm (BER) frequency than normal bowel. We investigate the use of a SQUID magnetometer to measure noninvasively the decrease in BER frequency associated with small bowel ischemia in a rabbit model.

Background

Smooth muscle of the small bowel exhibits two types of electrical activity: a regular, oscillating control activity known as the basic electrical rhythm (BER), and a high frequency spiking activity associated with muscular contraction [1]. The frequency of the BER in rabbits is normally about 15-20 cycles per minute (cpm). Occlusion of the mesenteric vessels that perfuse a section of the small bowel causes local ischemia that results in a decreased BER frequency, typically 8-12 cpm [2]. If blood flow is reestablished before irreversible damage occurs, the affected section of bowel will again become viable and the BER frequency will return to normal levels.

While serosal electrodes are most effective for directly observing the electrical activity of the intestinal smooth muscle, they are sensitive only to ischemia near the electrode and implanting them in an actually ill patient is not a viable alternative. Cutaneous electrodes have recently been used to detect small bowel electrical activity, but an extensive amount of filtering is necessary to extract usable signals from normal patients and small deviations from normal BER patterns may not be easily recognized [3]. The cutaneous potentials represent the summed contribution of electrically active sources in the abdomen that give rise to current on the abdominal surface and hence includes cardiac and gastric activity. This effect is amplified since the small bowel is normally insulated by several alternating layers of low conductivity fat and high conductivity muscle.

Superconducting QUantum Interference Device (SQUID) magnetometers can noninvasively detect bioelectric activity arising from the heart, brain, peripheral nerves, and smooth muscle. We have previously reported SQUID measurements of human small bowel BER which were evident in unfiltred data [4], which suggests that SQUID magnetometry is an alternative to cutaneous electrodes for noninvasive measurements. We present an application of SQUID magnetometry to the detection of small bowel ischemia in anesthetized rabbits, and a comparison of magnetic techniques with serosal and cutaneous potential recordings.

Methods

A midline laparotomy was performed on 6 anesthetized male New Zealand white rabbits and a distal segment of the small bowel exteriorized. The rabbits had been fed a nonmagnetic diet consisting of lettuce and cabbage for 72 hours prior to the experiment. Bipolar silver serosal electrodes were attached to the small bowel segment and a snare was placed around the mesenteric vessels innervating the segment. The snare, a 14 lb test monofilament fishing line threaded through a teflon tube, could be tightened and released from outside the abdomen. The bowel segment was attached to the abdominal wall with the electrodes underneath the bowel, and the laparotomy was closed. In two experiments, bipolar Ag-AgCl cutaneous electrodes were placed on the abdominal surface. The cutaneous electrodes could not be used consistently since they tend to interfere with the magnetometer recording. The animal was placed under a SQUID magnetometer with the section of the abdomen containing the attached segment of bowel placed to maximize the magnetic signals. We then recorded simultaneous cutaneous and serosal potentials, and transabdominal magnetic signals with a loose snare. After 15-25 minutes, the snare was tightened to induce ischemia to the segment of small bowel. Recordings of ischemia were taken for 30-60 minutes and the snare was again loosened, allowing blood to reperfuse the bowel, and an additional 15-25 minutes of data were taken.

Results

Figure 1 shows simultaneous transabdominal SQUID and serosal electrode recording of a small bowel segment before, during, and after an ischemic episode. Figure 2 shows power spectral density estimates of the same data using autoregressive spectral estimators. Notice that both figures show an obvious decrease of the BER frequency during ischemia and the subsequent return to pre-ischemic values on reperfusion. The dominant frequencies found by spectral analysis from serosal electrode and transabdominal magnetometer signals are highly correlated (R=0.98). Further, the difference...
Transabdominal Serosal Electrode SQUID

A) Baseline

B) Ischemic

C) Reperfused

Fig. 1. Transabdominal SQUID and serosal electrode recordings (A) under normal conditions, (B) fifteen minutes into an ischemic episode, and (C) five minutes after reperfusion.

Fig. 2. Power spectral density estimates of the signals in Fig. 1. The dominant frequency recorded by SQUIDs and by serosal electrodes decreases during ischemia.

between BER frequencies before and during ischemia, and the difference during and after ischemia is statistically significant according to paired Student’s t-tests (p<0.001 and p<0.04, respectively).

Discussion

We have demonstrated the ability of a SQUID magnetometer to track frequency changes in rabbit small bowel BER and confirmed that these changes are comparable to those of serosal electrode recordings. Cutaneous electrodes also appear to work well in the rabbit. However, human cutaneous recordings will contain much smaller contributions from the small bowel since alternating layers of fat and muscle tend to attenuate the flow of current. To illustrate this, we modified the experiment to include an insulating layer (part of a latex surgical glove) between the small bowel segment and the abdominal wall. Notice from Figure 3 that the presence of the insulator serves to significantly attenuate the cutaneous potential while leaving the serosal potential and transabdominal magnetic signal basically unaffected. A similar effect can be expected in human cutaneous potentials since the current must flow through at least three insulating layers: omentum, abdominal fat and subcutaneous fat.

These studies suggest that SQUID magnetometry may be a useful tool for clinical diagnosis of intestinal ischemia.

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References


