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Electrical Activity from Colon Overlaps with Normal Gastric Electrical Activity in Cutaneous Recordings

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The stability of EGG recordings is affected by a variety of artifacts. The aim of this study was to investigate possible overlapping of dominant frequencies in recorded cutaneous electrical activity arising simultaneously from the stomach and/or colon. Ten normal volunteers, eight posttotal colectomy patients, and four patients posttotal gastrectomy were studied. Fasting cutaneous recordings were obtained using four pediatric ECG electrodes attached to the abdominal surface. Electrical activity was recorded and digitally analyzed using custom-designed software. Spectral analysis after gastrectomy and colectomy showed persistence of power peaks in the gastric electrical activity range of frequency (2.5–3.75 cpm). In conclusion, noninvasively obtained colonic frequencies overlap EGG. This hypothesis is supported by the persistence of power peaks in the EGG range of frequency after gastrectomy and colectomy. Therefore, we conclude that contribution of electrical activity arising from the colon could substantially affect EGG recordings.

KEY WORDS: electrical control activity; gastric electrical activity; electrogastrogram; multichannel recording.

Noninvasive recordings of electrical signals from the gastrointestinal tract have been performed since Alvarez recorded the first electrogastrogram (EGG) in 1921 (1). These recordings display a sinusoidal wave pattern that represents with reasonable accuracy the overall internal gastric electrical activity (GEA) (2, 3). Visual analysis of this raw signal is very difficult due to the overlap of a variety of artifacts and external factors that affect the interpretation of EGG (4, 5). Despite many attempts to identify clinical applicability, this technique remained unutilized until computerized methods of signal acquisition and data analysis were introduced in the 1970s (6, 7). Computer methods for spectral analysis enhance the reliability of EGG to a certain extent, but important power peaks at frequencies different than physiological GEA are often present in the obtained EGG spectra. These frequencies are considered abnormal and termed bradygastria if under 2.5 cpm and tachygastria if above 3.75 cpm (5, 8–10). We previously reported that in acute canine experiments, and in a limited number of comparative internal GEA-EGG studies in humans, cutaneous electrodes recognized 80–85% of the frequency changes seen in simultaneous serosal recordings of GEA (3). Therefore, up to 25% of the events depicted in the EGG recordings are either artifacts or not associated with GEA at all.

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Most investigators agree that human colonic electrical control activity (ECA) *in vivo* is present in two major frequency ranges: 0–9 and 10–14 cpm. This broad spectrum of frequencies could be attributed to the utilization of many different methods of signal acquisition and data analysis (11–16). Studies designed to recognize these signals by surface electrodes have confirmed colonic activity from 1 to 7.5 cpm (17–20). Thus, colonic electrical activity may potentially overlap with the normal EGG, which could also mislead the interpretation of an EGG as abnormal based on the presence of frequency components different from those commonly accepted for the stomach. Other authors have reported this potential overlapping previously (18–21).

The aim of this study was to determine if electrical activity arising from the human colon could be recognized in the EGG range of frequencies using more sophisticated methods of acquisition and computer analysis.

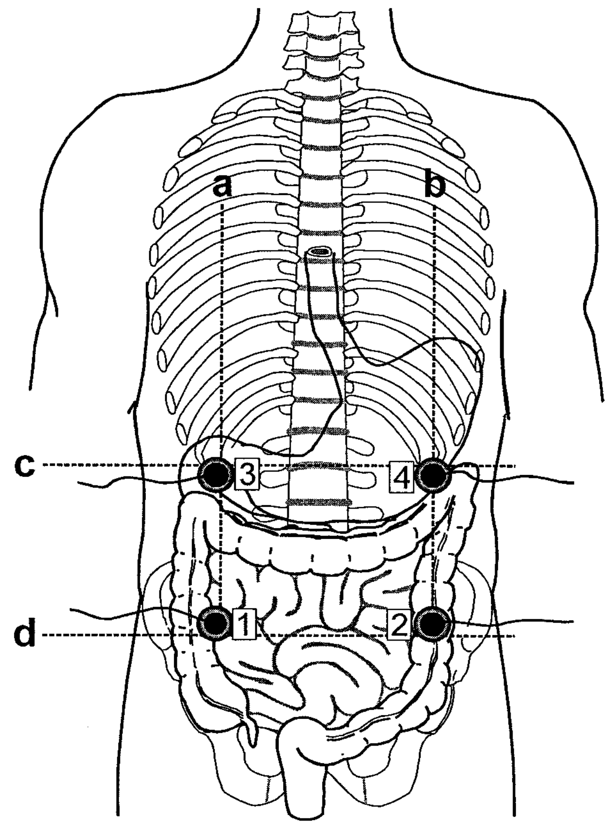

Fig 1. Electrode positioning and channels. Prolongation of the two midclavicular lines, (a, b) line between the inferior costal margins (c), line between the anterior superior iliac spines (d). Channel 1: electrodes 1–3 (right colon), channel 2: electrodes 2–4 (left colon), channel 3: electrodes 3 and 4 (EGG stomach).

MATERIALS AND METHODS

Ten normal volunteers (age 31.5 ± 4.4, male/female = 7/3) and eight posttotal colectomy patients (age 56.2 ± 17.8, male/female = 3/5) were studied, of which one subject also had recordings before colectomy. Four additional patients had recordings after total gastrectomy (age 56.2 ± 17.5, male/female = 2/2), of which one subject also had recordings before gastrectomy. The patients lay comfortably in a supine position in a quiet, dark room. The abdominal skin was scrubbed with isopropyl alcohol swabs and then prepared with ECG&EEG skin paste (D.O Weaver & Co, Aurora, Colorado, USA). Four active and one ground pediatric ECG electrodes (Neotrode 1720-003) with 78.5 mm^2 conducting surface area were attached to the abdominal surface. The location of the electrodes is shown on Figure 1. The following channel combinations were utilized: channel 1 (electrodes 1–3) following the abdominal projection of the longitudinal axis of the right colon; channel 2 (electrodes 2–4) following the abdominal projection of the longitudinal axis of the left colon; channel 3 (electrodes 3–4) following the abdominal projection of the gastric axis (EGG channel). Each study session consisted of 1 hr of recording following a fasting period of 6 hr.

Recording. The electrical activity was recorded on a custom-made multichannel recorder and conditioned using controlled bandpass preamplifiers (cutoff frequency of the single-pole Butterworth low-pass filter: 0.3 Hz; time constant of the single-pole Butterworth high-pass filter: 5 sec).

Data Analysis. The signals were digitized with a 10-Hz sampling frequency and filtered in a frequency band of 0.02–0.1 Hz using frequency sampling digital filter, assigning zeros to the unwanted frequency components (22). After filtering, the signals were resampled at 2 Hz, and digital spectral analysis was performed using custom-designed software developed in our laboratory (23). The power spectrum values from the entire recording time were displayed in pseudo three-dimensional (3-D) plots using frequency, power, and time as variables (24–26). The values in each individual spectrum were scaled as a percent of the dominant peak, which was normalized to 100%. Thus, only the dominant peaks (eg, stomach) were represented in the digital spectral analysis. Dominant peaks and their variability were analyzed in time–frequency plots using previously reported quantitative technique (23, 26).

Statistical analysis of the significance of the obtained values was performed using the Student's t test at $P < 0.01$ level.

RESULTS

The spectral analysis of channels facing the colon (channels 1 and 2) revealed the presence of dominant peaks at frequencies below 2.5 cpm in all subjects. The EGG channel (channel 3) displayed dominant peaks between 2.5 and 3.75 cpm (Figure 2) in normal volunteers and colectomized patients. Very little electrical activity was present in other frequency ranges.

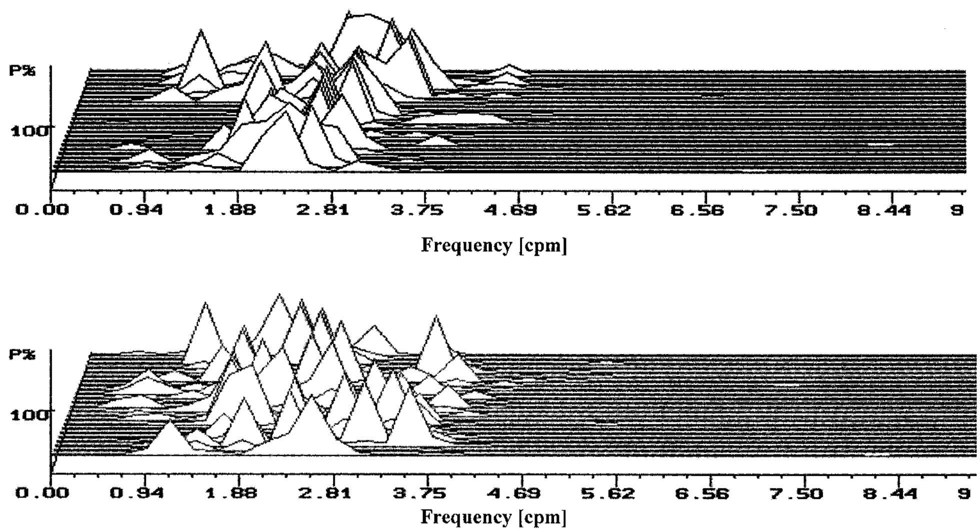

Fig 2. Pseudo-3-D plots of colonic channels 1 (right colon, top) and 2 (left colon, bottom) in a normal volunteer. Note the presence of power peaks in a broad range of frequencies with dominant peaks at 1–3.75 cpm in both channels.

After colectomy, power peaks at frequencies under 2.5 cpm diminished in colonic channels, resulting in a significant increase in the mean frequencies (Table 1). These changes were evident in the patient that had recordings before and after colectomy (Figure 3). Although the change in the mean frequency for the gastric channel was not statistically significant, there was an improvement in the stability of the EGG after colectomy (Table 1).

The gastrectomized patients displayed an intriguing outcome. After gastrectomy, the EGG channel exhibited a persistent presence of power peaks in the frequency range where normal GEA would be present. This pattern was demonstrated in the patient that had recordings before and after gastrectomy (Figure 4). The absence of gastric activity in all gastrectomized patients resulted in power increase of frequencies below 2.5 cpm, thus significantly decreasing the mean frequency in the EGG channel (Table 1). This change to a "bradygastric" range of frequencies was significant and very persistent, with a standard deviation of 0.20 cpm (Table 1).

DISCUSSION

The results obtained in this study indicate that colonic frequencies may overlap with gastric signals in cutaneous EGG recordings. Two facts support this hypothesis: (1) the persistent presence of power peaks in the normal GEA frequency range after gastrectomy and colectomy in the channel facing the stomach (Figure 4), and (2) the presence of predominant power peaks in the frequency range between 1 and 3.75 cpm observed in normal volunteers in the colonic channels 1 and 2 (Figure 2). This evidence strongly suggests that electrical activity different than that originating from the stomach might eventually be manifested in the spectral representation of EGG. This opens the question of the importance of the contribution of electrical activity arising simultaneously from different organs to normal or abnormal EGGs. In the range of tachygastria, power peaks may represent a small bowel component (~ 9 cpm) (20–27), respiration (~12 cpm), harmonics of the fundamental frequency (28, 29), and GEA uncoupling (30).

TABLE 1. MEAN FREQUENCY (CPM) OF CUTANEOUS ELECTRICAL RECORDINGS

Channel	Normals (mean ± SD)	Post-colectomy Mean ± SD	Post-colectomy P	Post-gastrectomy Mean ± SD	Post-gastrectomy P
Right colon	2.39 ± 0.31	2.74 ± 0.17	0.013	2.11 ± 0.24	NS
Left colon	2.36 ± 0.36	2.83 ± 0.25	< 0.01	2.20 ± 0.26	NS
Stomach	2.83 ± 0.29	2.73 ± 0.21	NS	2.07 ± 0.20	< 0.01

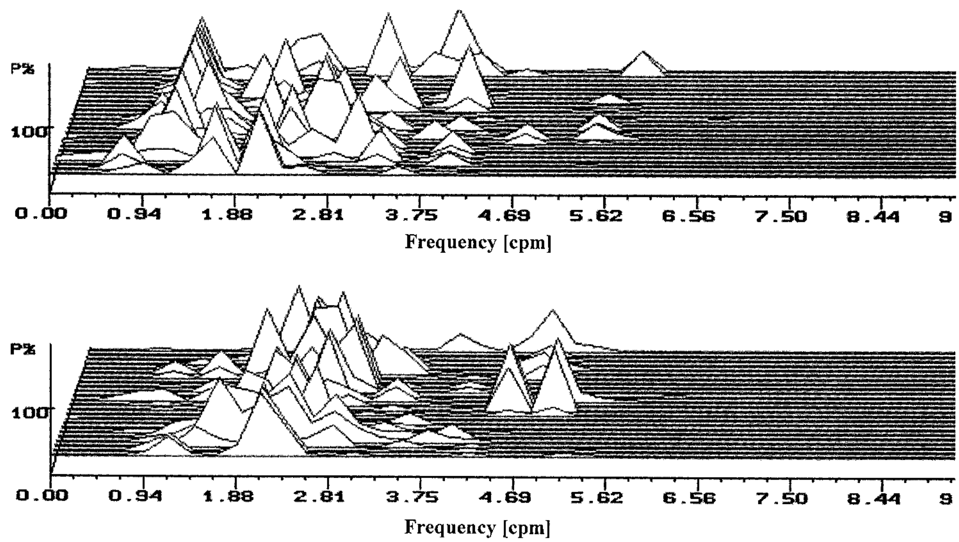

Fig 3. Pseudo-3-D plots of the same patient before (top) and after (bottom) total colectomy in the left colon projection (channel 2). There was a virtual disappearance of the frequencies below 2.5 cpm and persistence of frequencies in the GEA range.

The presence of power peaks in the range of bradygastria has been historically neglected and considered either an artifact or an abnormal gastric oscillator. Internal GEA recordings from humans, however, indicate that real bradygastric phenomena are extremely rare, if nonexistant (2, 3, 5, 9, 31).

In a recent study performed in human colonic strips, Rae et al (32) showed that slow waves arise in the circular muscular layer near the submucosa with a frequency of 2–4 cpm. Studies performed *in vivo* with electrodes implanted in the colonic subserosal layer and digitally analyzed have shown dominant low

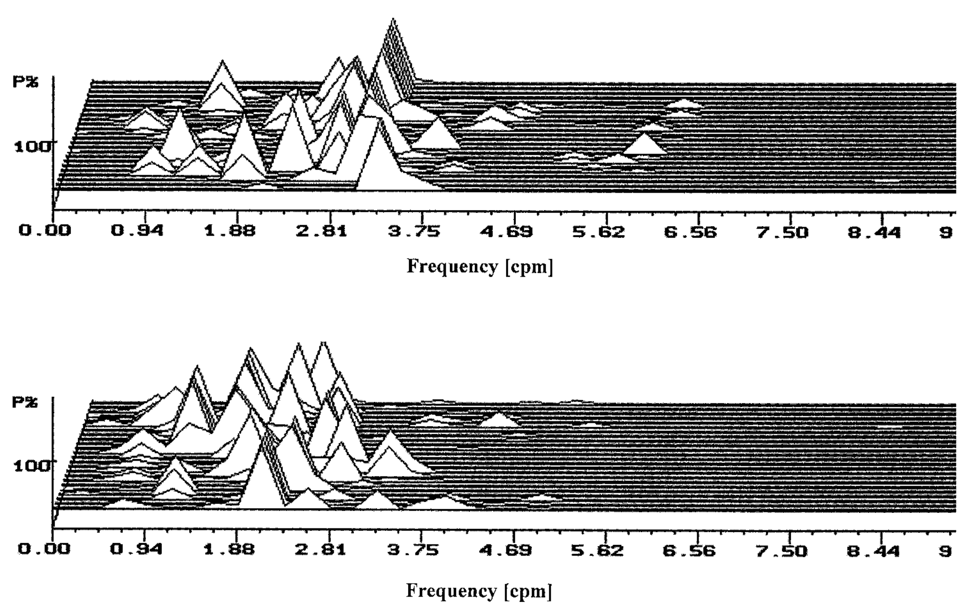

Fig 4. EGG (channel 3). Pseudo-3-D plots of the same patient before (top) and after (bottom) total gastrectomy. After gastrectomy, there was a decrease but not disappearance of power peaks in the GEA range of frequency. Notice that bradygastric frequencies seen in the pregastrectomy study may represent a colonic component characterized by a significant increase of the power peaks below 2.5 cpm after gastrectomy.

range frequencies of 2–4 cpm (14, 15). This was confirmed by Condon et al (33) in patients recovering from postoperative ileus with electrodes implanted in the circular layer of the colon.

Comparing human stomach and canine colon, *in vitro* ECA recordings from human colonic strips have displayed very low amplitude signals in the range of 1–12 mV that are difficult to distinguish from noise even using intracellular electrodes (32–34). This amplitude is variable and modified by different neurotransmitters, their analogs and inhibitors (34, 35). We have previously reported that due to technical complexities in the processes of EGG recording, amplification, and data analysis, EGG amplitude is also a function of external factors such as position, body mass index, interelectrode distance, active electrode surface area, and distance from the electrical oscillator to the electrodes (3, 4). In addition, the power dynamics of internal GEA are not well synchronized in different sections of the stomach due to the asynchronous (or chaotic) appearance of spike activity (36). Furthermore, distension of the atonic canine stomach with a balloon increased the amplitude of EGG signals even when gastric contractile action was abolished by atropine and glucagon (3). Thus, we concluded that absolute amplitude values and power dynamics should not be utilized as reliable parameters for EGG analysis in the present study. In the method we applied for spectral analysis (23), the values in each individual spectrum were scaled as a percent of the dominant peak, which was normalized at 100%. Thus, the absence of powerful components (eg, postgastrectomy) would result in the spectral representation of frequencies that otherwise would be overshadowed by the dominant peak.

After gastrectomy, the frequency peak around 2.5 cpm became dominant in all channels, confirming that lower frequencies most likely arise from the colon (Figure 4). These oscillators may explain some of the power peaks in the bradygastric range of frequency occasionally seen in the EGGs. Power peaks between 2.5 and 3.75 cpm (normogastric range of frequency) significantly diminished but did not disappear, suggesting that colonic activity may contribute electrical power to the frequency interval considered normal for EGG. After colectomy, there was a significant decrease in the power peaks below 2.5 cpm and persistent GEA power peaks (Figure 3). Therefore, in normal volunteers, it is very difficult to draw conclusions on the importance of the contribution of the colonic components at 3 cpm due to the overlap with gastric frequencies, which represent the dominant peak.

The results of our study showed predominant colonic frequencies from 1 to 3.75 cpm in normal volunteers (Figure 2), similar to the outcome of the experiments performed *in vitro* by Rae et al (32), and *in vivo* by Condon et al (33). The presence of these colonic components in EGG might be enhanced if the colon is full, distended, or overactive. Therefore, emptying the colon prior to standard EGG tests might be an avenue for improving the reliability of EGG for clinical applications. At this point, we have preliminary data suggesting that EGG recordings from healthy volunteers with an empty colon are more stable when compared to recordings from the same patients with an unprepared colon.

CONCLUSION

Electrical signals arising from the colon and recorded with cutaneous electrodes overlap spectrally with normal EGG. However, current methods of data acquisition and analysis make it extremely difficult to distinguish colonic from gastric components, particularly in the normogastric range (2.5–3.75 cpm) due to frequency overlap. The clinical relevance of the finding of bradygastria will need to be reconsidered.

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