Electrogastrography Can Recognize Gastric Electrical Uncoupling in Dogs

MARTIN P. MINTCHEV,*,† STANISLAW J. OTTO,* and KENNETH L. BOWES*
Departments of *Surgery and †Electrical Engineering, University of Alberta, Edmonton, Alberta, Canada

Background & Aims: Electrical uncoupling is the lack of electrical synchronization in different parts of the stomach. The ability of electrogastrography (EGG) to recognize gastric electrical uncoupling has not been adequately studied. The aim of this study was to determine the impact on EGG of surgically introduced gastric uncoupling in anesthesized dogs. *Methods:* Six pairs of bipolar electrodes were inserted into the antral gastric wall of 16 anesthetized dogs at laparotomy. Eight-channel bipolar cutaneous EGGs were simultaneously recorded. Three separate half-hour recordings were made from each dog in the basal state and after each of two circumferential cuts of all gastric muscle. The stomach was divided into three equally sized areas, each with an electrode pair in its anterior and posterior walls. Gastric electrical activity was assessed visually. EGG was digitized and processed by computer. *Results:* Criteria for EGG normality were defined from 9 dogs with normal gastric electrical activity. After the first antral cut, internal recordings from the area below the division were at a lower frequency and often irregular. The second cut produced three different frequencies. Suggested criteria for normality allowed correct recognition of 93% of all severely abnormal records. Records with mild gastric electrical abnormalities were recognized with a sensitivity of 74%. *Conclusions:* EGG can recognize severe electrical uncoupling.

Cutaneous recordings of gastric electrical activity (GEA) using electrogastrography (EGGs) are reliable in recognizing gastric electrical frequency.[1,2] However, no objective quantitative studies (internal and cutaneous recordings) have been performed to investigate the ability of EGG to recognize varying degrees of gastric electrical uncoupling. Electrical uncoupling is the lack of electrical synchronization between different parts of the stomach.[1,2] When uncoupling is present, different parts of the stomach generate signals at different frequencies. Changes in gastric electrical frequency without changes in coupling have been described[3–5] and may be of some clinical value. However, it is unlikely that a minor change in gastric electrical frequency would dramatically affect gastric motor function provided the normal coupling pattern is preserved. On the other hand, abnormal electrical uncoupling would inevitably affect gastric motor function. Noninvasive recognition of gastric electrical uncoupling could be of significant clinical value.[5]

Coupling of gastric electrical signals in internal recordings is recognized as persistently similar time shifts between successive slow waves obtained from different gastric recording sites. Ideally, antral electrical uncoupling would be measurable using the EGG method if EGGs were reliable in recognizing consistent and significant time shifts between proximal and distal channels. Despite one encouraging report,[6] later studies[2,7] showed that time shifts recorded cutaneously are insignificant and inconsistent with the time shifts seen internally with implanted electrodes. Moreover, it has been shown that the distance between different parts of the stomach wall and the recording abdominal electrodes is a major factor in the averaging effect of the electrical phenomena occurring in different sections of the stomach.[8] An EGG electrode pair would record from a much greater area of the stomach (if not from the whole organ) than the implanted serosal electrode pairs.[2,8] Finally, several external factors (such as the body mass index, the active surface areas of the recording electrodes, and the interelectrode distances) contribute to the overall unreliability of the EGG time shifts as an avenue to study gastric electrical uncoupling.[7] An alternative way to investigate the direction of propagation of GEA from EGG by exploring the dynamics of the EGG waveforms[9] was also shown to be unreliable because of the fact that many healthy subjects showed occasional changes in the EGG waveforms.[7]

In this study, we suggest and explore a new approach to recognize gastric electrical uncoupling with EGG. This is a comparative investigation in dogs of the effect of surgically created gastric electrical uncoupling on the most reliable EGG parameter and its dynamics, the EGG frequency.

Abbreviations used in this paper: cpm, cycles per minute; EGG, electrogastrogram/electrogastrography; GEA, gastric electrical activity; MF, mean frequency; PDF, probability density function.

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A

Cutaneous Canine EGG

Channel	Electrode Combination
7	1 - 2
8	2 - 3
9	3 - 4
10	4 - 5
11	1 - 3
12	1 - 4
13	2 - 5
14	1 - 5

B

Internal Canine GEA

Channel	Electrode Combination
1	a - b
2	c - d
3	e - f
4	g - h
5	i - j
6	k - l

C

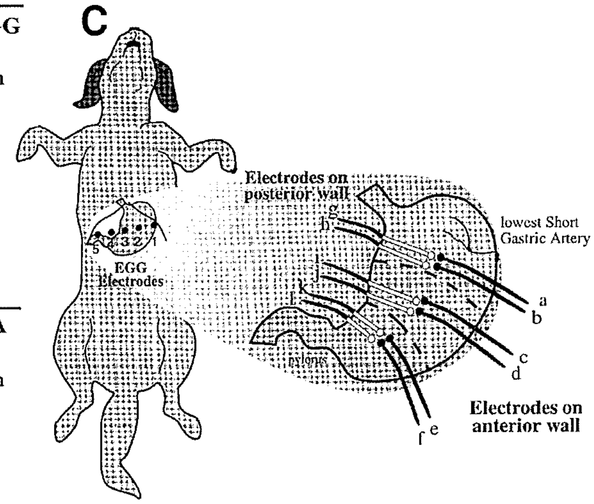

Figure 1. (*A* and *B*) Electrode combinations and (*C*) electrode positions used for EGG and internal GEA recordings. Internal electrode wires g–l were implanted on the posterior gastric wall. The distance between successive internal pairs (e.g., a-b, c-d) was approximately 4–6 cm, and the interelectrode distance in any given pair was 3–4 mm. Cutaneous electrodes were overlaying the internal pairs and were 3.5–4 cm apart.

Materials and Methods

Six stainless steel pairs of bipolar electrodes were inserted into the antral gastric wall (three anterior and three posterior) of 16 dogs under Pentothal anesthesia (Abbott, Montreal, Quebec, Canada) at laparotomy. The initial dosage of anesthetic was 30 mg/kg and was supplemented with 3 mg/kg as needed, based on monitoring the restoration of the blinking reflex. The two distances from the pylorus to the esophageal entry on the lesser curvature and from the pylorus to the lowest short gastric artery were measured. The sites for future divisions of the stomach were selected at one third and two thirds of these distances; this delineated three approximately equal portions of the stomach. A pair of implanted stainless steel wire electrodes was placed on the anterior and posterior wall of each portion. In addition, five standard neonatal electrocardiogram electrodes (ConMed Andover Medical, Haverhill, MA) were positioned along the abdominal projection of the stomach axis (Figure 1). Eight-channel bipolar cutaneous EGG were recorded using a technique described previously.[2] Three separate 14-channel (6 internal and 8 cutaneous) half-hour recording sessions were made from each dog in the basal state and after each of two circumferential divisions of all gastric muscle. Each line of division was at the site previously delineated. After the first half-hour basal recording, the first cut was performed separating the two distal electrode pairs from the rest. Another half-hour recording session followed. Finally, the second circumferential cut physically divided the stomach into three separate sections, each of them having two pairs of implanted electrodes (one on the anterior and one on the posterior serosal wall). This second cut was also followed by a third half-hour recording session from all electrodes (internal and cutaneous). The divisions were performed with cautery and individual ligation of larger vessels. Bleeding was minimal. The divided portions of the stomach were not reanastomosed, but left in their normal positions. The blood supply to each segment was carefully preserved by not dividing any of the vessels on the lesser or greater curvature. The abdominal wall was closed after each incision before starting the respective recording session. Locations of the EGG electrodes were constant throughout the experiment. During all recording sessions the anesthesized dogs lay quietly in supine positions. Because the reliability of EGG amplitude is questionable[2,7] and uncoupling is a phenomenon related exclusively to GEA rhythm, we did not study the amplitude changes in GEA and EGG.

The experiments were approved by the Animal Welfare Committee of the Faculty of Medicine at the University of Alberta (Edmonton, Alberta, Canada).

GEA recorded with internal electrodes was assessed visually. Uncoupling was defined as persistent (more than four consecutive periods) deviation from parallelism of the lines connecting corresponding peaks in GEA recorded from different channels. This deviation should have exceeded at least $^1/_4$ of the average period of the fastest of the GEA signals in the given time interval. Frequency irregularity was defined as more than 25% change in the next period of the GEA in a given channel.[2] Signals were defined in categories A–I as follows: (A) normal signals, no visible uncoupling or irregularities were noted; (B) mild uncoupling, uncoupling was noted in 1–2 internal GEA channels for at least $^1/_4$ of the total recording time; (C) severe uncoupling, uncoupling was noted in more than two internal GEA channels for more than $^1/_4$ of the total recording time; (D) mild irregularities, irregularities of gastric electrical frequency were noted in 1–2 internal GEA channel for at least $^1/_4$ of the total recording time; (E) severe irregularities, irregularities of gastric electrical frequency were noted in more than two internal GEA channel for more than $^1/_4$ of the total recording time; (F) mild uncoupling and mild irregularities, a combination of categories B and D; (G) severe uncoupling and severe irregularities, a combination of categories C and E; (H) mild uncoupling and severe irregularities, a combination of categories B and E; and (I) severe uncoupling and mild irregularities, a combination of categories C and D.

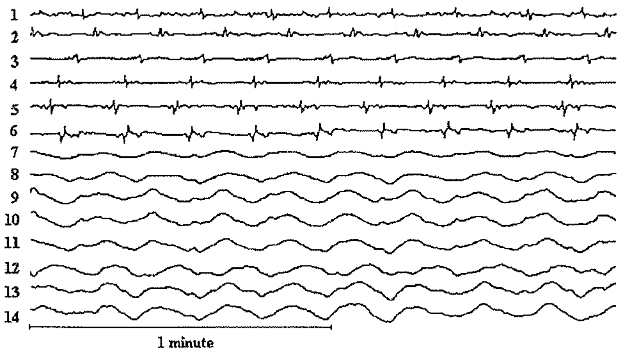

Figure 2. Typical 2-minute basal recording. Channels 1–6 are internal and 7–14 are cutaneous EGG. Good regularity and electrical coupling were present in internal channels.

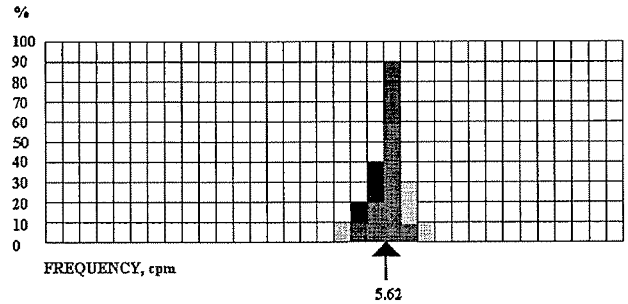

Figure 3. Overlapping PDFs of the MF values calculated from the EGG channels of a typical basal recording. The functions were bell-shaped, and their maxima coincided.

EGG was digitized (10-Hz sampling frequency), bandpass filtered (frequency sampling filters, frequency band of 0.02–0.2 Hz) and processed by computer. After digital filtering, the sampling frequency was reduced to 2 Hz. The fast Hartley transform (a real-number alternative of the fast Fourier transform, a technique that calculates frequency spectra from given time intervals,[10]) was used to obtain successive frequency spectra for 4.27-minute time intervals with 75% overlap. The spectra were arranged in three-dimensional frequency plots.[11] The dominant spectral component in each spectrum was considered representative of the gastric mean frequency (MF) value in the given 4.27-minute time interval. Successive MF values were arranged in a specially designed time-frequency plot for each individual EGG channel.[7] Standard deviation of the MF values in each channel was calculated and used to quantify the stability of EGG. In addition, the probability density function (PDF or the frequency distribution[7]) of the MF values in the given channel was also obtained and used to identify the different dominant frequencies present in different EGG channels.

The sensitivity (S) of the computerized EGG test was calculated as the ratio between the number of dogs with abnormal GEA recognized by EGG (NEGG) and the total number of dogs with abnormal GEA determined by the internal recordings (TOTN): S = (NEGG/TOTN) × 100, % [1].

Table 1. Typical Basic Statistical Averages of MF Values

Channels	Mean (*cpm*)	Standard deviation (*cpm*)
7	5.63	0.12
8	5.72	0.24
9	5.59	0.13
10	5.62	0.00
11	5.61	0.17
12	5.63	0.11
13	5.62	0.00
14	5.62	0.00

NOTE. Values calculated from EGG channels 7–14 (in the experimental setup) of a dog during the basal period. Standard deviations of at least 6 of 8 channels are within the normal range of 0.2 cpm.

The frequency spectra of EGG were examined separately when a clear pattern of internal uncoupling was present, and the percentage of EGG spectra that clearly identified the presence of different internal frequencies was calculated.

Results

EGG normality was defined from 9 dogs with normal GEA (category A, Figure 2) determined by visual inspection of the internal recordings from the basal recording session using the following criteria: (1) mean gastric frequency between 4.1 and 6.5 cycles per minute (cpm); (2) standard deviations of the MF values of <0.2 cpm in at least 6 of 8 channels (Table 1); and (3) PDFs in at least 6 of 8 channels were bell-shaped and showed

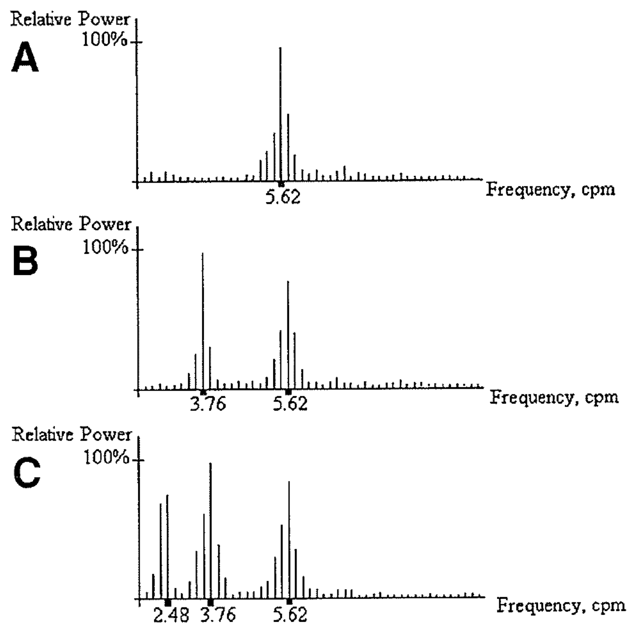

Figure 4. (*A*) EGG frequency spectrum of normal dog. Some EGG spectra (*B*) after the first circumferential cut and (*C*) after the second circumferential cut showed multiple dominant frequencies simultaneously seen in the internal recordings.

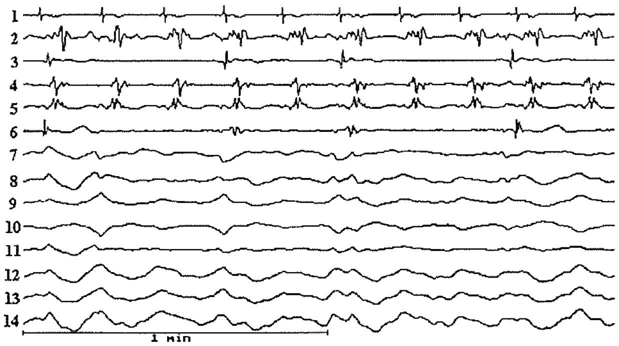

Figure 5. Two-minute recording of uncoupled canine stomach after the first circumferential cut. Although uncoupling is seen in the internal channels (3 and 6), some EGG channels (e.g., 12, 13, and 14) are not visually different from normal.

coinciding maxima of 3 adjacent peaks (step of 0.23 cpm) containing 80% of all frequencies present (Figure 3). A typical EGG frequency spectrum of a normal dog is shown in Figure 4*A*.

During the basal recording sessions, 6 of the 16 dogs showed irregularities of GEA while preserving the pattern of electrical coupling (category D). Computer evaluation of the EGG signals obtained from 4 of these animals showed an unstable frequency that manifested itself as an increment in standard deviations of MF values beyond the set limits (criterion 2). However, PDFs of the MF values remained in the normal range. The EGGs from the other 2 dogs in this group met the criteria for normality.

One of the 16 dogs showed mild gastric electrical uncoupling in the basal state (category B). This phenomenon manifested itself cutaneously with both increased standard deviations of the MF values, and broadening of their PDFs beyond the set limits (criteria 2 and 3).

In the basal state the overall sensitivity of the computerized EGG test was found to be 71.4% for recognition of all types of mild electrical abnormalities, whereas the sensitivity for recognition of mild frequency irregularity alone was slightly lower, 66.7%.

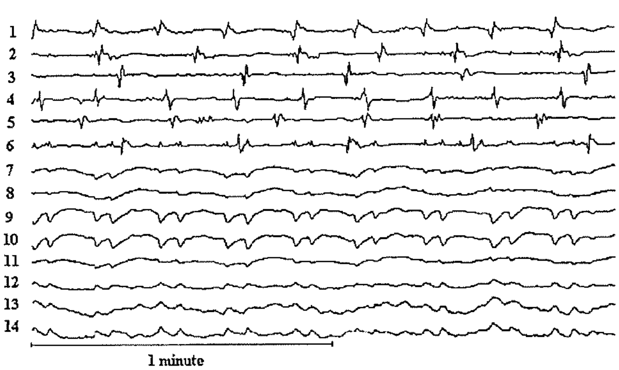

Figure 6. Two-minute recording classified in category C. Severe uncoupling is seen in the internal channels (1–6), although frequency irregularities are not evident. Some EGG channels show higher frequency probably because of the superposition of the uncoupled internal electrical phenomena.

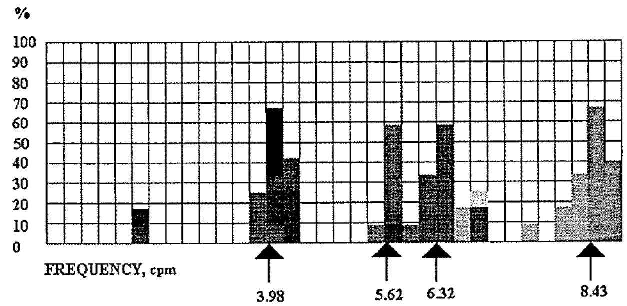

Figure 7. PDFs of the MF values calculated from different EGG channels after the second antral cut. Several frequency areas are seen, and the maxima did not coincide. Some of the higher frequencies in the plot were not seen in the internal GEA recordings.

The first antral cut uncoupled the antrum below the division in all 16 dogs, and recordings from that area were usually at a lower frequency (Figure 5). In 10 of 16 dogs, frequency irregularities were also present (category F). In 7 of 10 dogs in this category, EGG was abnormal showing higher standard deviations and broad PDF plots (criteria 2 and 3 were not met), but in 3 of 10 dogs, the EGG was normal. The sensitivity for this category was 70%.

Five of the 6 dogs with only uncoupling distal to the cut (Category B) were abnormal according to the EGG criteria for normality, a sensitivity of 83.3%.

The overall sensitivity of the computerized EGG test in discovering invoked mild gastric electrical abnormalities was 76.7%. However, only 46.4% of all EGG frequency spectra clearly displayed the two gastric electrical frequencies from above and below the cut (Figure 4*B*).

The second antral cut resulted in three uncoupled gastric regions in all dogs. Frequency irregularities were also present in 14 of 16 dogs (category G). In 2 dogs, separate

Table 2. Typical Basic Statistical Averages of MF Values

Channels	Mean (*cpm*)	Standard deviation (*cpm*)
7	6.07	0.76
8	5.27	1.28
9	7.93	1.19
10	6.33	0.24
11	6.07	0.94
12	3.81	0.76
13	5.41	1.14
14	6.02	1.25

NOTE. Values calculated from EGG channels 7–14 (in the experimental setup) of a dog after the second antral cut. High standard deviations are observed.

regular frequencies were seen in each of the three regions (category C). Thirteen of the 14 dogs with uncoupling and frequency irregularities showed an abnormal EGG using the criteria for normality. Both dogs with regular uncoupled frequencies were also abnormal (Figures 6 and 7). Typical statistical averages of the MF values calculated from recordings after the second antral cut are shown in Table 2. Three areas of oscillations were clearly seen in only 35.2% of all EGG frequency spectra (Figure 4*C*).

Although the computerized EGG test could be regarded as quite sensitive in discovering severe gastric electrical abnormalities (the test was 93% and 100% sensitive for categories G and C, respectively), mild abnormalities (categories B, D, and F) were recognized cutaneously in 17 of 23 cases with a test sensitivity of 74%.

Discussion

The motor function of the distal stomach is under the control of extrinsic and intrinsic nerves and the intrinsic myogenic GEA. Although neural input is probably essential for gastric contractions, GEA controls the frequency and direction of propagation. If different gastric sites are electrically uncoupled, gastric motor function would inevitably be affected. For this reason, assessment of gastric electrical uncoupling is vital when studying gastric motor function. Two possible methods for noninvasive assessments of gastric electrical uncoupling were suggested previously.[5,6] Unfortunately, both were shown to be unreliable for clinical applications.[2,7] In the present study, a new method for evaluating gastric electrical uncoupling is used. The cornerstone of the method is a technique for quantification of EGG based on a definition of normality derived from simultaneous recordings of internal GEA and EGG in normal dogs. A similar technique to quantify EGG has been used previously on awake healthy volunteers, both in the fasting postprandial state.[7] The derived criteria for normality were used to determine the sensitivity of the method in discovering surgically introduced mild and severe gastric electrical uncoupling. The method allowed correct recognition of all abnormal records classified with internally determined severe uncoupling (category C), and it was 93% sensitive in the recognition of records classified with severe uncoupling combined with frequency irregularities (category G). However, it failed to recognize 2 of 6 records with mild frequency irregularities (category D) in the basal state, 3 of 10 records with mild frequency irregularities combined with mild electrical uncoupling (category F), and 1 of 6 records with mild uncoupling after the first antral cut (category B). The overall sensitivity of the computerized EGG test for mild gastric electrical abnormalities in the present study was found to be 74%, meaning that 26% of patients with mild gastric electrical abnormalities could be misleadingly diagnosed as normal. This may be related to the fact that only a minor part of the smooth muscle was dysrhythmic, or uncoupled from the rest. The impact of this dysrhythmic/uncoupled part on EGG (an integral representation of all electrical events in the stomach seen from slightly different perspective[8]), probably was not always significant. Interestingly, some cutaneous EGG channels displayed an increased frequency without internal tachygastria (Figure 4). This phenomenon is probably because of the superposition of GEA from many sites in EGG. This cutaneous superposition of the internal GEA may be the reason only a minority of the EGG spectra clearly displayed the several (2 or 3) distinct GEA frequencies present internally after the divisions of the stomach. After the invoked uncoupling, the majority of the EGG spectra showed significant change with presence of frequencies different than the actual internal frequencies, which implies that some cutaneously recognized "tachygastrias" or "bradygastrias," and particularly "gastric dysrhythmias"[3,4,12] may be related to gastric electrical uncoupling, rather than to a real internal brady/tachygastria, or arrhythmia.

Conclusion

This study suggests that EGGs, if processed properly by computer, are reliable in recognizing severe gastric electrical uncoupling. However, mild or inconsistent gastric electrical uncoupling may not be evident in EGG signals and the sensitivity of the test in such situations is lower.

EGG could be regarded as a distant overview (or a mixture) of many electrical events that occur in different sections of the stomach. Consequently, gastric electrical uncoupling and gastric electrical irregularities (or frequency disturbances) may manifest themselves cutaneously in a similar fashion. However, an EGG record quantified as abnormal using the proposed technique would reliably indicate a severe gastric electrical abnormality. However, minor abnormalities might be missed.

The suggested technique could be a possible avenue towards more reliable assessment of EGGs.

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Address requests for reprints to: Kenneth L. Bowes, M.D., 2D4.47 Walter MacKenzie Centre, Department of Surgery, University of Alberta, Edmonton, Alberta, Canada T6G 2B7. e-mail: kbowes@gpu.srv.ualberta.ca; Fax: (403) 492-5069.

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