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REVIEW ARTICLE

Electrogastrography

Current Assessment and Future Perspectives

THOMAS L. ABELL, MD, and JUAN-R. MALAGELADA, MD

"Electrogastrography" is a term generally applied to the measurement of human gastric electrical activity. Electrogastrography has been known since the 1920s but has not received widespread acceptance, either as a research technique or a clinical tool in gastroenterology. Early turn-of-the-century electrocardiograms were reported to have a "wandering baseline" that could not be explained by known cardiac physiology. In retrospect, those baseline changes were probably caused by electrogastrographic signals, which were soon filtered out as electrocardiographic recording technology progressed (1). In 1922, Walter Alvarez, using cutaneous electrodes applied to the epigastric region, intentionally recorded the first electrogastrogram, or EGG (2). Electrogastrography has continued since then to attract the interest of physiologists, psychophysiologists, and gastroenterologists. In the last two decades, interest in cutaneous electrogastrography has increased more rapidly, paralleling advancements in electronic equipment and electrical instrumentation. Part of this increased interest in electrogastrography has been the association of gastric electrical abnormalities with several clinical syndromes, which has stimulated further research interest at both physiological and clinical levels. As a developing research tool, and as a technique with possible clinical application, electrogastrography may be of interest to gastroenterologists as well as to any physicians who diagnose and treat individuals with gastrointestinal complaints.

This paper reviews the current physiological understanding of the electrogastrogram as a measure of gastric electrical activity, as well as the current techniques for its measurement. In addition, this paper introduces the reader to the pathophysiological significance of the electrogastrogram, its association with several clinical syndromes, and its potential research and diagnostic applications.

WHAT IS ELECTROGASTROGRAPHY?

Electrogastrography can measure gastric electrical activity in several ways, either "internally," that is, mucosally or serosally, or "externally," that is, cutaneously. In this review, we concentrate on mucosal and cutaneous recordings, since serosal recordings involve surgical implantation of electrodes, which prevents their widespread clinical use. Furthermore, since most investigators have concentrated on either "internal" EGG recordings (more often in dogs than in man) or "external" EGG recordings (more often in man than in dogs), this paper will deal with those recording sites separately. More recently, investigators have performed simultaneous internal and external EGG recordings, sometimes including concomitant measurements of gastric motor activity (3–5).

The electrical activity recorded by the EGG emanates primarily from the muscularis propria, which constitutes the largest mass of muscle tissue in the stomach. Muscle from different anatomic regions of the stomach exhibits different electrophysiologic charcteristics: the smooth muscle of the more proximal one third of the stomach representing an area of sustained membrane polarity, and the distal two thirds, an area of phasic membrane depolarization. Electrical changes in the uppermost part of the

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From the Gastroenterology Unit, Mayo Clinic and Foundation, Rochester, Minnesota.

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Dr. Abell's current address: Division of Gastroenterology, University of Tennessee, Memphis, Tennessee.

Address for reprint requests: Dr. Juan-R. Malagelada, Hospital Valle de Hebron, Carretera Valle de Hebron s/n, 08035 Barcelona, Spain.

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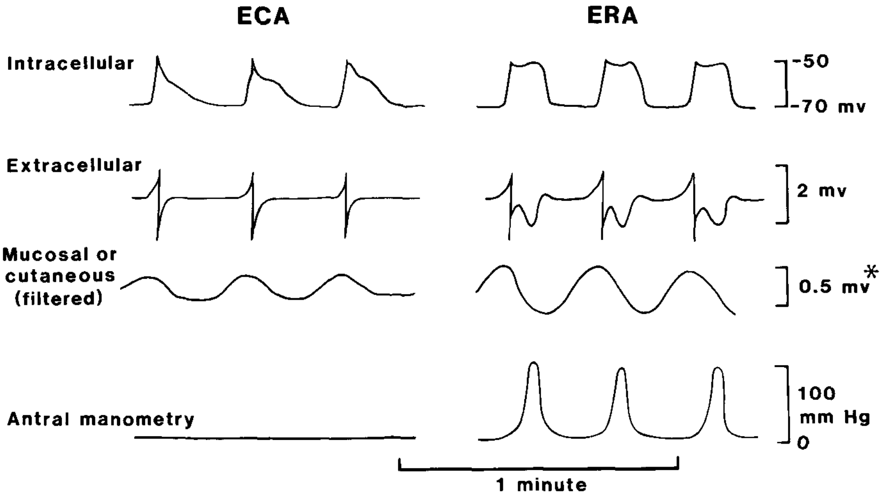

Fig 1. Stylized representation of intracellular, extracellular, and mucosal or cutaneous (filtered) electrogastrographic signals, with accompanying manometric activity. Electrical control activity (ECA) and electrical response activity (ERA) are both represented. Electrical control activity may cause some contractile activity but does not result in gastric peristalsis and is usually not detected by manometry. (*Voltage shown is for cutaneous recording; mucosal recordings approach 2 mV.)

stomach are small in magnitude, and thus this area is electrogastrographically silent. The midcorpus area on the greater curvature constitutes *de facto* a pacemaker area (6–8) from which phasic electrical activity propagates along the longitudinal muscle layer distally to the pylorus (8, 9).

Terminologic problems have arisen in electrogastrography, partly as a result of the different descriptive terms for gastric electrophysiology. Current thinking separates phasic gastric electrical activity into two basic categories: electrical control activity (ECA) and electrical response activity (ERA) (Figure 1). Several equivalent terms have been used to describe these two basic categories, and Table 1 lists a number of these terms, in relationship to ECA and ERA. This paper will use the term "electrical control activity" for the periodically occurring potential change which does not result in peristalsis and "electrical response activity" for the increase in plateau depolarization which leads to muscle contraction and gastrointestinal peristalsis. Thus, ECA is not associated with gastric peristaltic activity, although the initial depolarization peak may cause a small contraction [type I wave of Code (9)]. ERA represents an increase in plateau depolarization (potentiated in the distal antrum by superimposed electrical spikes), raising it above the threshold for smooth muscle contraction, leading to peristaltic activity. ERA is therefore associated with a gastric peristaltic contraction [type II wave of Code (9)] which is mechanically significant, particularly in the trituration and propulsion of solids (10) (Figure 1). After feeding, there is an increase in the amplitude of recorded EGG signals that is

TABLE 1. GLOSSARY OF TERMS FOR GASTRIC ELECTRICAL ACTIVITY

Electrical control activity (ECA)	*Electrical response activity (ERA)*
Basal electrical rhythm (BER)	Fast activity
Initial potential	Second potential
q and k waves	w wave
Slow wave	Second (slow) component spike or spike potentials
Pacesetter potential (PSP or PP)	
First component	
Control potential	
Control wave	
(Cyclic depolarization without contraction)	(Increase in plateau potential, leading to contraction)

assumed to correspond to a transformation from ECA to ERA and thus to mechanical activity. Also, the frequency of the signal decreases temporarily after feeding (11).

EGG SIGNAL CONFIGURATION AND CUTANEOUS ELECTROGASTROGRAPHY

The shape of the EGG varies, depending on recording location, that is, intracellularly, extracellularly (mucosally or serosally), or externally (cutaneously). Intracellular recordings are not easily attainable *in vivo*. However, extracellular EGG recordings have been obtained with both surgical (for example, sutured electrodes) and nonsurgical (for example, suction or magnetic electrode) techniques. Extracellular EGG recordings have a different configuration than do the intracellular wave forms (12). This difference can be explained in part by core–conductor, or cable, theory, which states that the extracellular signal approximates the first-time derivative of the intracellularly recorded signal (13, 14). The extracellular wave forms vary somewhat, depending on whether they are recorded monopolarly or bipolarly.

The wave form of cutaneous EGG signals differs from both the intracellular and the extracellular recordings. This difference can be explained in part by describing electronic potentials generated by gastric cells as "dipoles" (12). This description results in the cutaneous EGG signal appearing as a "sine" wave and representing waves of depolarization dipoles (ECA or mechanically inactive stomach) or waves of both depolarization and repolarization dipoles (ERA or mechanically active stomach) (13) (Figure 1). EGG recordings, whether mucosal or cutaneous, both measure gastric electrical activity; but there exist important differences between them. Mucosal EGG tracings measure the potential difference between one or more electrodes (15); for example, a bipolar mucosal electrode with a distance of 1 cm between electrodes measures the potential difference between those points. Cutaneous electrodes measure potential differences over larger areas; for example, bipolar abdominal EGG electrodes reflect the potential difference between both electrodes, and this difference may be the summation of "dipoles" of a relatively large area of the stomach.

The cutaneous EGG is obtained via electrodes applied to the abdominal skin. Most investigators use silver or silver chloride electrodes, either of their own making or one of the many commercially available types (for example, NDM Silvon stress test; Hewlett Packard 14245A, Narco Type 155, or 3M Red Dot 2256). Cutaneous electrogastrography can be performed with either "monopolar" (one active and one reference electrode) or "bipolar" (two active and one ground electrode) configurations. There seems to be no consensus between monopolar and bipolar arrangements; however, in many instances, bipolar signals seem to provide a superior signal-to-noise ratio (11, 13). Most investigators perform some sort of skin preparation to minimize DC signals and drift.

Electrogastrography requires electrical "filtration" of the recorded signals to remove unwanted signals, such as cardiac, respiratory, duodenal, and colonic signals. However, filtering removes potentially useful information. Thus, in selecting a filter system, one must strike a balance between enhancing the desired signal and overlooking meaningful data contained in the filtered-out signals. Most investigators use a filter system adjacent to the electrode to record the cutaneous EGG (12, 16, 17). However, signal filtration can also be achieved by using computer assistance, which is discussed in the Appendix.

The desired gastric electrical signal in humans occurs approximately three or four times a minute, or roughly every 20 sec, which (since 1 Hertz equals one cycle per second) is equivalent to 1/20 Hz or 0.05 Hz. Most EGG filters aim at eliminating higher-frequency signals, chiefly cardiac (frequency, 1 Hz) and respiration (frequency, 0.2 Hz), without affecting the EGG signal. Some filter designs also reduce lower-frequency signals, such as electrode baseline changes (frequency less than 0.03 Hz). A typical EGG filter combination would thus consist of a "high-frequency filter" of greater than 0.2 Hz (to remove signals faster than 1 cycle every 5 sec) and a "low-frequency filter" of less than 0.03 Hz (to remove signals slower than 1 cycle every 33 sec). However, conventional filters (which are subject to the limitations of electronic circuits) do not remove all the signal above or below a specific frequency (Figure 2), and thus some of the "undesired" frequencies may in fact appear on the final EGG tracing.

The EGG signal is then amplified via "high-impedance differential instrumentation" amplifiers, which amplify and further filter the EGG signal, often in several "steps" or stages. These amplifiers are electrically isolated to remove the risk of elec-

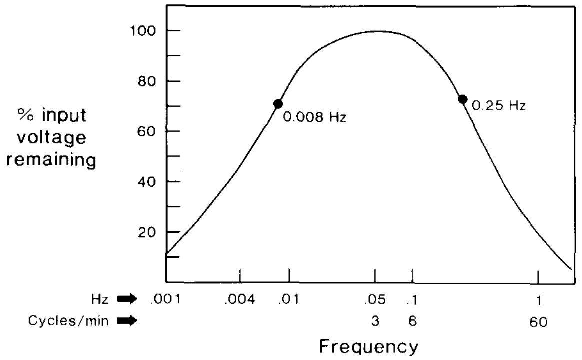

Fig 2. Representation of "frequency response curve" for standard electrical filter. In this system, desired electrical frequencies in range of 0.05 Hz are left unchanged. Other frequencies are filtered, with varying degrees of "roll-off" represented by slope of curve. Assigned "cutoff frequencies" are typically located at about 70% level (for example, 0.08 Hz and 0.25 Hz). Signals with frequencies much larger or smaller than desired frequency are thus partially removed, so that desired frequency predominates.

trical shock to the individual being studied (Figure 3). The EGG signal, as well as any other physiologic signals recorded simultaneously (such as respiration, cardiac frequency, and gastric manometry), is then recorded on a standard chart recorder (Figure 4), although some systems also record onto magnetic tape or computer disk (Figure 3), either directly or via a "split" signal.

The optimal placement of cutaneous EGG electrodes has been surrounded by considerable controversy. Both abdominal and extremity locations have been used for EGG recordings with monopolar or bipolar arrangements (12, 18), although the most common placement for "active" electrodes is abdominal. Recent work has concluded that a bipolar abdominal electrode placement along the proximal to distal "antral axis" is the most satisfactory (19). The "antral axis" can be described as lying along a line passing from the proximal to the distal portion of the stomach in the direction of normal electrical and mechanical propagation. The "antral axis" may differ in both location and direction (or slope) depending on the type (eg, J-shaped stomach, horizontal stomach) and size of stomach. The advantage of this bipolar approach along the antral axis derives from empirical observations that it provides the most consistent EGG recording quality (19). Good-quality EGG recordings are defined as containing predominantly gastric electrical signal, with a minimum of other electrical signals present. For placement of electrodes without the benefit of fluoroscopy, the lower rib cage is the most widely used reference point (13, 18–20). Electrode placement by reference to the umbilicus is to be avoided, because of unreliability (20).

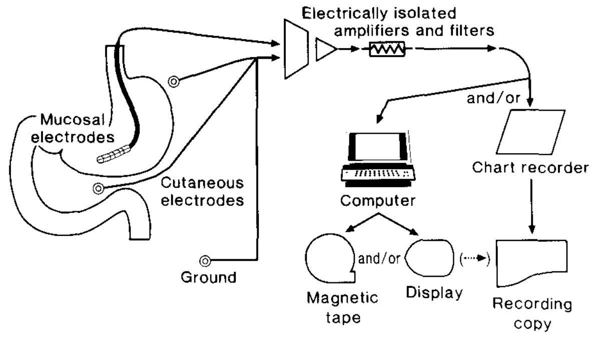

Fig 3. Schematic representation of electrogastrographic recording system. Mucosal and cutaneous signals are amplified and filtered through electrically isolated system in several steps or "stages." They are then recorded on analog system (recorder) or digital format (computer). Digitalized data may also be converted back to analog and displayed on screen.

Other electrical signals originating in either skeletal or smooth muscle may affect EGG signals, resulting in less than optimal recording quality. This is true particularly for cardiac, respiratory, duodenal, and colonic signals, which are incompletely filtered. Electrical interferences with frequencies approaching that of the human EGG signal (for example, respiratory and duodenal signals, both approximately 0.2 Hz) cannot be completely removed by filtering, resulting in difficulties in both EGG recording and in tracing interpretation (Figure 2). The problem can be overcome, at least in part, by concomitant recording of respiratory motion (by pneumograph) and by empirical realigning of the epigastric electrodes to reduce or exclude the duodenal signal (20, 21). Nevertheless, the possibility of overinterpreting the interference of these extragastric signals as electrical rhythm abnormalities is a real one (Figure 5). Conversely, focal gastric electrical disturbances may be obscured by the mass of normally depolarizing dipoles, so that these abnormalities are underrecognized by cutaneous electrogastrography (see Appendix for further discussion of signal analysis).

MUCOSAL ELECTROGASTROGRAPHY

In mucosal EGG recordings, both suction and magnetic force have been used for electrode attachment. Although oral intubation is necessary for electrode placement, mucosal recordings are nevertheless nonoperative procedures. Mucosal electrodes provide signal tracings approaching those

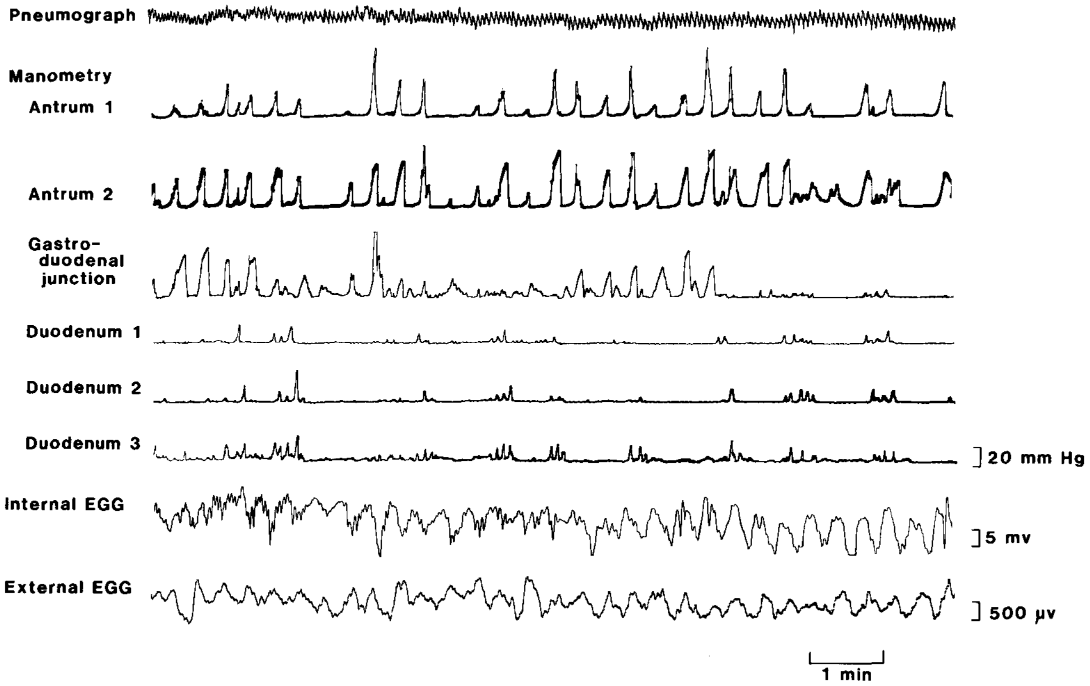

Fig 4. Simultaneous gastric electromanometry in man: postprandial recording in normal volunteer. Two channels of antral, one channel of gastroduodenal, and three of duodenal manometry are shown. Internal electrogastrogram (EGG) is recorded with mucosal electrodes held in place by magnetic force, and external EGG is recorded with cutaneous electrodes. Note absence of respiratory artifacts in first channel.

obtained through serosally implanted electrodes (13, 22). Thus mucosal recordings can be regarded as a direct reflection of extracellular gastric electrical activity (Figures 1 and 6), and they can be used

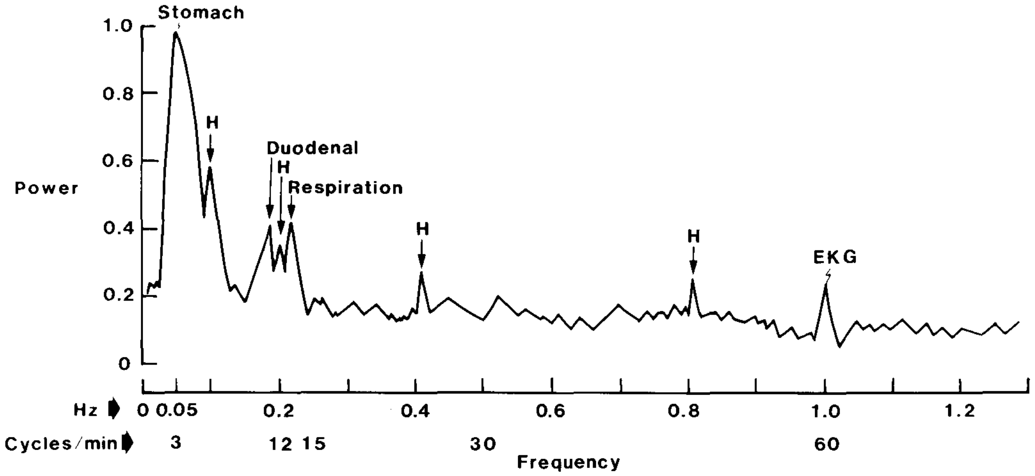

Fig 5. Location of representative frequencies in electrogastrographic frequency spectral analysis. This is a stylized representation of "power spectrum" of signals recorded with standard electrogastrographic system. Normal gastric electrical frequency ("fundamental" frequency, at 0.05 Hz or 3 cycles/min) is represented with greater "power," because normal gastric electrical frequency contributes a relatively larger portion of recorded signal frequencies. Duodenal and respiratory signals have similar frequencies and sometimes cannot be completely separated from each other. Likewise, harmonics (H) of fundamental frequency (at 0.1, 0.2, 0.4, and 0.8 Hz) may appear, further complicating separation and identification of frequencies. Electrocardiographic (ECG) signal is more completely filtered by recording system and thus has less "power." (See Appendix for further explanation.)

Fig 6. Comparison of serosal and mucosal recordings in anesthetized dog. First channel shows mucosal recording obtained with platinum electrode held in place by magnetic force. Serosal electrodes are sutured in corpus and proximal and distal antrum. Note the episodes of tachygastria and bradygastria which are demonstrated by both the mucosal and serosal electrodes.

as a means of evaluating the validity of cutaneous electrogastrography. However, mucosal electrogastrography is also fraught with difficulties and potential artifacts.

Several problems are associated with use of suction electrodes to obtain mucosal EGG recordings. One is that the use of suction electrodes has resulted in successful recordings of good quality for only limited periods. Presumably, electrodes detach for a variety of reasons, such as excess gastric movement and decreased suction from mucus buildup in the suction channel. Also, because suction electrodes cannot be used in the fed state, their usefulness for both experimental and clinical observations is limited (20). Use of magnetic force to maintain the luminal electrode in apposition with the anterior gastric wall has recently been described (21). This technique has promise and may overcome some of the deficiencies of suction electrodes, but experience is still limited.

Mucosal EGG recordings can be obtained with both monopolar and bipolar electrodes, the main difference being one of wave form shape (13). Most mucosal recordings have been obtained with bipolar electrodes of either platinum or silver (22, 23). The resultant EGG recording is then filtered, amplified, and recorded; the system used is similar, if not identical, to the system used for cutaneous EGG recordings (Figure 3).

Our observation has been that the interfering effect of extragastric electrical signals (such as cardiac, respiratory, and duodenal) appears to be less prominent on the mucosal EGG than on the cutaneous EGG recordings. If this is true, the reason may be that the intragastric electrode is closer to the smooth muscle layers of the stomach, so that the EGG signal is stronger than the other electrical signals in the body.

ANALYSIS OF ELECTROGASTROGRAPHIC SIGNALS

The analysis of EGG signals has been the subject of much controversy. Tracing analysis can be accomplished either visually or with the aid of computers. Mucosal EGG tracings have usually been interpreted visually (20, 24). Cutaneous EGG tracings, in contrast, have increasingly been analyzed by computer techniques, often employing some form of frequency analysis (13, 18, 25). Two possible reasons account for the greater use of computer analysis of cutaneous recordings than of mucosal. First, cutaneous EGG recordings have been performed for much longer periods than mucosal EGG recordings, at least in the past. Therefore, the length of tracing to be analyzed has tended to be greater with cutaneous EGG. Second, the cutaneous EGG signal is usually more obscured by interfering signals and other artifacts that make its visual interpretation over relatively short intervals more difficult.

Visual analysis, whether of mucosal or cutaneous recordings, is, nevertheless, the most straightforward. Simple inspection of the recordings can provide some information about amplitude, frequency, and wave forms. In addition, hand-scored analytical techniques can help assess relative trends over time in any of these three variables. Problems arise, however, because many EGG tracings are not of good enough quality to allow reliable visual inspection or scoring. One solution to this problem would be to improve the quality of cutaneous or mucosal EGG signals through better electrode construction and placement complemented by more advanced filtration and amplification systems. However, steps in this direction occur gradually. Computer analysis was developed as an attempt to, first, analyze large amounts of data over time and, second, to extract information on signal frequency out of tracings with blurred signals unsuitable for visual analysis (Figure 5). The latter use, as discussed more thoroughly in the Appendix, is somewhat risky for its potential to "create" nonexistent data. The combination of clear recordings amenable to visual inspection and computer-assisted analysis would offer the best of all possibilities.

PATHOPHYSIOLOGIC SIGNIFICANCE OF ELECTROGASTROGRAPHY

The pathophysiologic significance of the EGG is based on documentation of disordered EGG signals, including abnormalities of both electrical rate and rhythm. Several forms of gastric electrical dysrhythmias have been recognized and several forms of dysrhythmia have been associated with clinical conditions in gastroenterology. As indicated earlier, an increase and a decrease in the electrical pacesetter rate are referred to as "tachygastria" and "bradygastria," respectively. No standardized definition of the two terms has yet become accepted, although most authors have proposed both a rate criterion and a duration criterion; that is, if the basal rate is 3–4 cycle/min (in man), tachygastria might be defined as greater than 5 cycle/min and bradygastria as less than 2 cycle/min, each lasting at least 1 min. (The rate criterion for dogs would involve different numbers, since the basal rate in dogs is 4–5 cycle/min.) Another form of dysrhythmia consists of a disorganization of the normal rhythm with irregular resting membrane potentials (often with segments of increased rate) and an aberrant wave form. This third type has been designated "mixed" or "tachybradyarrhythmia."

Gastric electrical dysrhythmias have been investigated *in vitro* in experimental models and in clinical conditions in humans. Abnormalities in smooth muscle electrical activity and their effect on electromechanical coupling have been investigated *in vitro* by use of antral muscle strips. Recent *in vitro* research has demonstrated a role for prostaglandins (PG) in the physiology of gastric muscle (26). In one study, antral muscle strips were removed from five dogs to study the effect of a prostaglandin inhibitor (indomethacin) on the electrical and mechanical function of isolated antral muscle. The antral muscle strips were exposed to both indomethacin and PGE_2, and the resulting data suggest that prostaglandins in antral muscle may increase the frequency of electrical slow waves and decrease the contractile activity associated with those slow waves (26). This experimental procedure was applied to antral muscle taken from a 26-year-old female with a history of gastric retention who had undergone a gastrojejunostomy to provide symptom relief. Antral muscle strips from this patient studied *in vitro* demonstrated action potentials at an increased rate without plateau potentials. Indomethacin was then added to deplete the muscle strips of PGE_2, and 1 hr after the addition of indomethacin, normal action potentials occurred, accompanied by increased contractile amplitude. This effect was then blocked by the readdition of PGE_2 (26). This research suggests that some dysrhythmias may result from alterations in the intraluminal milieu or from local release of PGE_2 or other bioactive substances known to exist in the gastric wall.

Spontaneous gastric dysrhythmias were first observed incidentally in dogs fitted with implanted serosal electrodes for physiologic studies (27–29). Some otherwise healthy-appearing animals exhibited runs of tachygastria during phase I and phase III of the interdigestive cycle (27, 28). These spontaneous dysrhythmias are usually, but not invariably, abolished by feeding (27). Recent work has shown that bradygastria and mixed dysrhythmias can also occur spontaneously. Spontaneous electrical dysrhythmias are more common in the early postoperative period after laparotomy (6) and in recently vagotomized animals (30).

Canine dysrhythmias can also be induced pharmacologically by several drugs (including epinephrine, PGE_2, met-enkephalin, and glucagon) injected either intravenously or directly into the gastric arterial supply (31–33) (Table 2). Dysrhythmias can be induced pharmacologically in the fasting and fed states, but the sensitivity of the stomach is more than three times lower postcibally than during fasting (34). Although spontaneous and drug-induced

TABLE 2. DYSRHYTHMIA AGENTS (DOG AND MAN)

Drug	*Used in dog or man*	*Dysrhythmia dose*	*References*
Prostaglandin E_2	M*	10^{-6} M	26
	D	5.2 μg/kg (fasting) and 16.6 μg/kg (fed), IA bolus	32, 34
β-Endorphin	D	40 μg/kg/hr, IV infusion, and 2 mg/kg, IV bolus	31
Met-enkephalin	D	40 μg/kg/hr, IV infusion, and 2 mg/kg, IV bolus	31
	D	11.1 μg/kg (fasting) and 35.1 μg/kg (fed), IA bolus	32, 34
Insulin	M†	0.2 IU/kg, IV	36
Secretin	M†	0.25 + 2.0 clinical units/kg/hr, IV	36
Glucagon	M†	2, 5, 10 μg/kg, IV bolus	36
	M	7 μg/kg, infusion IV	21
	D	61 μg/kg (fasting) and >221 μg/kg (fed), IA bolus	32, 34
Pentagastrin	M†	6 μg/kg, IM bolus	36
Cholecystokinin/ pancreozymin	M†	1.0 + 16.0 Crick, Harper, Roper units, kg/hr	36
Epinephrine	D	100 μg/kg/hr IA	33
	D	1.7 μg/kg (fasting) and 16.6 μg/kg (fed), IA bolus	32, 34

*In vitro.
†In postvagotomy patients.

dysrhythmias are electrophysiologically indistinguishable, each major form of dysrhythmia has some characteristics of its own. Tachygastria usually arises as an ectopic rhythm in the distal antrum and propagates retrogradely (22, 27, 32, 35). Bradygastria, in contrast, usually develops in the corpus and antrum, and its pacesetter potentials propagate aborally (32). Thus, the cutaneous EGG may aid in the detection of "focal" antral dysrhythmias as they propagate to other areas of the stomach.

Gastric contractile activity may be absent during tachygastria (33). In chronic dog models, tachygastria, be it spontaneous or pharmacologically induced, is usually associated with a flattening of plateau potentials. However, in some instances in which tachygastria and bradygastria coexist (mixed dysrhythmia), some pacesetter potentials may be followed by electromechanically significant plateau potentials and associated contractions.

In humans, dysrhythmias similar in their electrophysiologic characteristics to those observed in dogs have been recorded with surgically implanted serosal electrodes (36). Spontaneous gastric dysrhythmias in healthy humans, at variance with observations in apparently healthy dogs, are rare and short in duration (often <2 min) (5, 21). There is also an analogy between man and dog for dysrhythmic agents. Insulin, secretin, cholecystokinin, pentagastrin, and glucagon have all shown dysrhythmic potential (as detected by both implanted and cutaneous electrodes) when administered to postoperative (36) or symptomatic (33, 36) patients (Table 2). In a recent study, we showed by simultaneous mucosal and cutaneous electrogastrography that intravenously administered glucagon at pharmacologic doses consistently induces gastric dysrhythmias in normal individuals (21).

Reports of EGG abnormalities in patients with a variety of clinical conditions began appearing in the late 1950s (37, 38). Initially, the EGG technique was used primarily for psychophysiological studies investigating the effects of sensorial stimulation, acute stress, or chronic illness upon gastric electrical rhythm (39–46). These psychophysiologic studies have been performed only with cutaneous EGG, and correlation with internal EGG or gastric mechanical activity is not available. In addition, the conditions have not been standardized, and controls and rigid experimental design are not always provided. However, it might be fruitful to explore this field in the future with the aid of improved technical and statistical methodology, including more rigorous experimental design.

Harvey et al (47) obtained mucosal EGGs with balloon-mounted electrodes in patients with prior gastric surgery for ulcer disease and described electrical abnormalities in several patients afflicted with dumping syndrome. A stronger case for pathogenetic involvement of gastric dysrhythmia in symptomatic dysfunction of the stomach was presented by Telander et al (35). Their patient was a 5-month-old male infant with gastric distension and inability to eat. At laparotomy, intraoperative gastric electrical recordings showed an antral focus of tachygastria fixing at a frequency of 4.7 cycle/min and retrograde propagation of electrical potentials.

Following these earlier, isolated reports, more systematic gastric electrical activity in patients with symptoms of gastric dysfunction was increasingly reported. You et al (22), using both mucosal and surgically implanted serosal electrodes, found abnormal antral myoelectrical activity in nine of 14 symptomatic patients with unexplained nausea, bloating, and vomiting. However, in seven of 25 subjects studied, mucosal EGG signals could not be recorded, because of technical factors, such as poor electrode contact. Cutaneous electrodes were not used for these studies, and in another recent article, the same group has continued to use mainly surgically implanted electrodes (48). Support for these observations has been provided by a recent study involving patients with ulcer disease (with and without gastrointestinal symptoms), patients with unexplained nausea and vomiting, and healthy controls who underwent cutaneous EGG recordings in the postcibal period. Tachygastria and other dysrhythmias were observed in both symptomatic ulcer patients and a subgroup of patients with unexplained nausea and vomiting (49). In addition, a recent study of five patients (four of them diabetic) with chronic nausea and vomiting and delayed gastric emptying showed evidence of tachygastria or tachyarrhythmia associated with nausea when studied while fasting (5).

The clinical significance of these electrogastrographic abnormalities is still uncertain, partly because EGG abnormalities have not been shown to be more than "associated with" specific gastrointestinal diseases. Even if certain EGG findings can be shown to be reliably associated with specific gastric pathologic conditions, the association is not necessarily causal. The role of electrogastrography in investigating functional types of upper gastrointestinal symptoms is beginning to be explored (50).

FUTURE PROSPECTS

More than 60 years ago, Walter Alvarez predicted that the EGG would reveal: (1) peculiar types of peristalsis, (2) conditions under which they would be found, and (3) symptoms with which they would be associated (2).

Despite Alverez' (and others') predictions, electrogastrography has yet to fill a well-defined role in gastroenterology. From a technical standpoint, it will be necessary to continue to improve the quality of signal recording, both internally and externally. For the external EGG, optimal electrode positioning remains a problem, and multiple electrode locations need to be explored, perhaps by techniques of external electrical "mapping" of the stomach. For mucosal EGG, an improvement in electrode design will be required to determine the best shape, material, and cable conduction system. Improved signal quality will also require improvements in apposition of the electrode to the mucosa.

More extensive studies correlating EGG signals with gastric contractile activity and verifying EGG representations of phases of the digestive cycle will be necessary. Furthermore, there is a need for correlation between EGG and gastric emptying, humoral responses, and other postcibal functions.

Computer-assisted analysis needs to be further validated with simultaneous internal recordings of electrical and mechanical activity. Pattern recognition combined with better signal recording may overcome the problem of distinguishing electrical dysrhythmia from other physiologic signals and may also help in recognizing bradygastria and brief periods of dysrhythmia.

In addition, investigations into the significance of electrogastric dysrhythmias must continue. These investigations need to include dysrhythmic mechanisms, association with gastrointestinal disorders, and, should electrical dysrhythmias prove to be clinically significant, methods of treatment. Electrogastrography now seems to be on the verge of acceptance as a research tool in gastroenterology. Once it can be established as a research tool, its potential for clinical usefulness can begin to be assessed.

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APPENDIX

Various computer-assisted techniques have been developed to assist in EGG interpretation and analysis (18, 25). Since much of the current EGG literature uses many of these computer-assisted techniques, a review of these techniques may prove useful to an understanding of electrogastrography. Most methods incorporate a frequency analysis routine that allows them to assess the frequency content, or "power spectrum," of EGG signals. This routine involves transferring the analog (wave form) signal into digital (numerical) form, and these digitized data are then dealt with. Since converting every wave form into numerical equivalents would result in an excess number of data, analog data (wave forms) are sampled at regular recurring intervals to obtain data representative of all the waveforms.

These sampled data are next analyzed according to any of several accepted mathematical models, to result in "frequency spectral" analyses (11). These computer-assisted frequency analysis methods involve separating the wave form data into various frequency components and then designating the relative contributions of a given frequency (to the whole signal) as the "power" of that frequency. For example, a "frequency analysis" of an EGG signal may have the greatest contribution of its frequencies in the range of 3–4 cycle/min (the "fundamental" frequency) and thus have greater "power" at that frequency. The EGG may also (in some cases) contain additional electrical frequencies originating in other smooth and skeletal muscle areas of the body, but these frequencies may have less "power" (Figure 5).

A newer approach to computer analysis of EGG signals, sometimes referred to as "running spectral analysis," involves the use of a frequency spectral analysis over time (18). In this technique, frequency spectra from EGG signals are computed at regular intervals, and the resultant frequency spectra are displayed over time, so that two-dimensional displays, that is, time versus frequency spectra, are produced (18). The addition of a third variable, the power of the frequencies reported, can be used to create a "pseudo-three-dimensional plot" representing the frequency spectrum and the frequency "power" over time.

Several disadvantages to computer analysis need to be considered as well. First, computers are valuable adjuvants for data analysis, but one should be wary of using them as primary generators of data. Computer processing of EGG signals has the potential to distort data, especially if the limitations of computer analysis are not understood. The "running" spectral analysis may actually "blur" dysrhythmic changes, such as brief intermittent tachygastria or bradygastria. The band range between normal gastric frequency (3–4/min) and duodenal frequency (11/min) is actually quite narrow. Numerous frequency peaks may appear in this band, including harmonics of gastric frequency, respiration, and extravisceral artifacts (Figure 5). Thus, it may be difficult, without an independent reference, to distinguish these physiologic frequencies from gastric dysrhythmia. Computer analysis of EGG signals, because it can be quite complex, may not be easily understood by persons not skilled in its interpretation and may thus be limited in its acceptance in the medical community. It may also add time and expense to EGG interpretation. Advances in EGG recording techniques resulting in improved signal quality and reliability may provide the ultimate validation and acceptance of computer-assisted EGG analysis.

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