What Is Measured in Electrogastrography?

A.J.P.M. SMOUT, MD, E.J. VAN DER SCHEE, MSc, and J.L. GRASHUIS, PhD

The object of this study was to elucidate what is actually measured in electrogastrography. Comparison of gastric signals simultaneously recorded from serosal and cutaneous electrodes in the conscious dog led to the following findings: 1. In the absence of phasic contractile activity and electrical response activity (ERA), the cutaneous recordings contained a frequency corresponding to the fundamental frequency of the electrical control activity (ECA) of the stomach (about 0.08 Hz). 2. Tachygastrias gave rise to cutaneous signals containing the tachygastric frequency (about 0.25 Hz). 3. The amplitude of the electrogastrogram increased when ERA occurred. It is concluded that both ECA and ERA are reflected in the electrogastrogram. A model is proposed that describes the electrogastrogram as the result of field potentials generated by depolarization and repolarization dipoles.

Electrogastrography (EGG) is the name given to the recording of gastric electrical activity from cutaneous electrodes. (In analogy with terms like electrocardiography and electroencephalography, it seems wise to reserve the term EGG for cutaneous recording and to renounce its use for intraluminal and serosal recording of gastric potentials.) Since 1922 (1) a limited number of investigators have published studies on EGG, mostly in man. Agreement exists on the sinusoidal configuration of the EGG signal and on its frequency in man, about 3 cycles per minute (0.05 Hz). The gastric origin of the signal was proven or claimed to be proven by several authors (1-6), but convincing evidence was provided only recently by Brown et al. (7) and Smallwood (8).

A question of major importance, which has not yet been answered satisfactorily, concerns what exactly is measured in EGG. Most earlier investigators concluded or assumed that the electrogastrogram reflects the phasic contractile activity of the stomach. Due to a lack of knowledge of gastric myoelectric activity, the mechanism by which this reflection is achieved could not be elucidated. It has been suggested that contraction-induced changes in the electrical impedance of the abdomen play a role in the generation of the electrogastrogram (9).

Studies made during the past 15 years yielded much information about the electrical activity of gastric smooth muscle. It is now known that in the extracellular signal derived with serosal electrodes two kinds of electrical activity can be distinguished. The first kind, often referred to as electrical control activity (ECA), is an omnipresent periodic activity that is not indicative of contractile activity. The second kind, the so-called electrical response activity (ERA), is time-locked to the ECA, but only occurs in connection with phasic contractile activity.

Brown et al (7) concluded from their experiments in man that gastric ECA is the only source of the electrogastrographic signal. This conclusion is in contrast with the assumption that in electrogastrography phasic contractile activity is measured.

The possibility that gastric ERA contributes to the surface signal has not yet been suggested as such in literature.

The object of this study was to identify the source(s) of the electrogastrogram. The principal method used to achieve this goal was the com-

Manuscript received May 1, 1979; revised manuscript received August 30, 1979; accepted October 11, 1979.

From the Department of Medical Technology, Faculty of Medicine, Erasmus University, Rotterdam.

Address for reprint requests: Dr. A.J.P.M. Smout, Dept. of Medical Technology, Erasmus University, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands.

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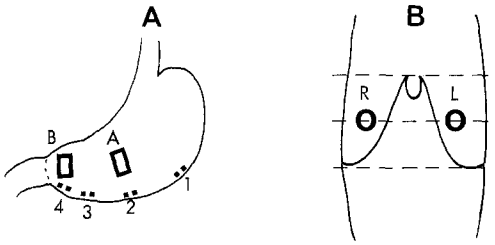

Fig 1. Positions of serosal and cutaneous electrodes and force transducers. (A) Bipolar serosal electrodes 1, 2, 3, and 4 placed along the greater curvature at 12, 7, 4, and 2 cm from the pylorus respectively. Force transducers A and B opposite electrodes 2 and 4. (B) Abdominal surface electrodes R and L were placed 8 cm apart on a transverse line midway between the lower end of the body of the sternum and the lowest point of the costal arch.

parison of the electrical signals simultaneously derived from the gastric wall and the skin of the conscious dog.

MATERIALS AND METHODS

Four healthy dogs (beagles), weighing between 10 and 14 kg, were used. Four bipolar electrodes were sutured to the serosal surface of the stomach (Figure 1A) under general anesthesia (induction with thiopental sodium, maintenance with nitrous oxide and enflurane) and using a sterile operating technique. In dogs 1, 3, and 4 two extraluminal strain-gage transducers were placed in a transverse direction opposite electrodes 2 and 4. The serosal electrodes consisted of two silver/silver chloride conical tips, 3 mm long, base diameter 0.2 mm, mounted 2 mm apart in a small plate. The electrode wires were connected to a 6-channel radio transmitter (10) implanted subcutaneously (dog 2), or to a multipin connector implanted in the animal's neck. For cutaneous recording disposable silver/silver chloride ECG electrodes (14245A, Hewlett Packard) were used. Before placement of these electrodes some electrolyte paste (Redux Paste, Hewlett Packard) was rubbed on the shaved skin. Two electrodes were placed on the abdominal skin at sites selected in preliminary experiments (Figure 1B).

Recordings were made in the conscious state, starting one week after operation. On each dog weekly recording sessions, lasting from 1 to 16 hr, were carried out for at least 2 months. During recording sessions the dogs lay unrestrained in a measuring cage similar to their normal housing. Recordings were made both in the fasting and in the postprandial state. When not subjected to fasting, the dogs were fed *ad libitum* with a dry food (Canex).

Recordings were made on curvilinear pen recorders (Van Gogh EP-8B) and on magnetic tape (Racal Store 14). In the bipolar serosal recordings connections were such that an upward deflection indicated that the proximal electrode was positive with respect to the distal and, in the cutaneous recordings, that the right abdominal electrode was positive with respect to the left one. The recordings of the bipolar serosal signals were made with cut-off frequencies of high- and low-pass filters (6 dB/oct) at 0.5 and 15 Hz, respectively. For cutaneous recordings the filters were set at 0.012 and 0.46 Hz. These latter filter settings were chosen for adequate elimination of baseline shifts and electrocardiogram. In addition to the bipolar

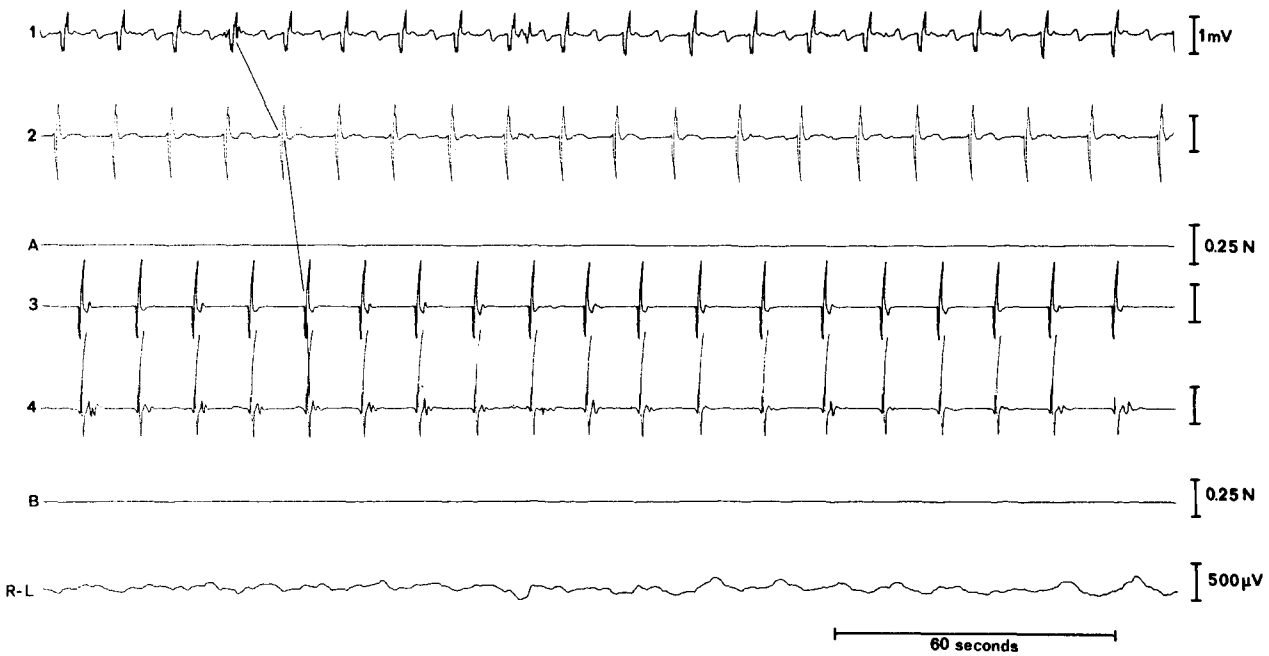

Fig 2. Recording of gastric myoelectrical and mechanical activity (bipolar serosal electrodes 1, 2, 3, and 4; strain gages A and B) and the corresponding cutaneous signal (R-L). Motor quiescence phase.

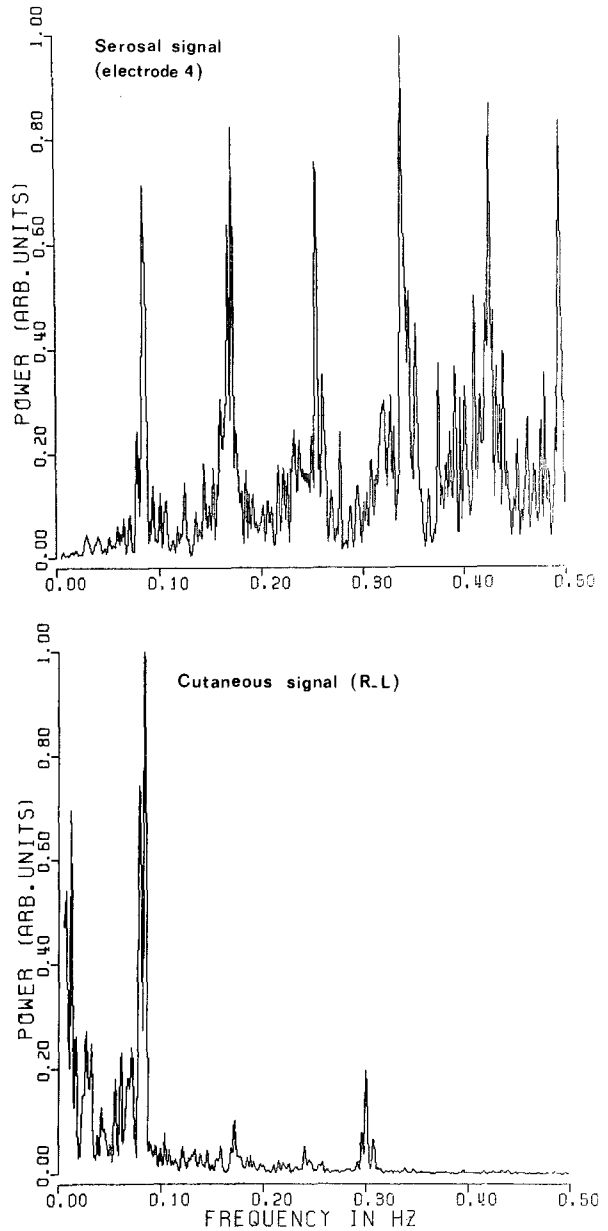

Fig 3. Smoothed power spectra of signals simultaneously derived from serosal electrode 4 (upper spectrum) and cutaneous electrodes (lower spectrum). The duration of the analyzed stretch, part of which is shown in Figure 2, was 17.07 min. The peak at 0.30 Hz in the lower spectrum is probably of duodenal origin. The very low frequency peaks in the lower spectrum are in part due to noise originating in the electrode-skin interface and in part of unknown origin. Motor quiescence phase.

serosal recordings, unipolar serosal recordings were made in dogs 3 and 4. The reference electrode (14245A, Hewlett Packard) was placed on the right hind leg. The records were divided into blocks of 1024-sec (17.07-min) duration and analyzed by means of visual examination and by means of fast Fourier transform, using a NOVA-2 minicomputer.

RESULTS

In total 530 blocks of 17.07 min were recorded. In 22 of these (4.2%) the cutaneous signal contained so much noise (mainly motion artifacts) that analysis was impossible. Figure 2 illustrates the types of signals obtained from serosal electrodes, force transducers and cutaneous electrodes during absence of ERA [as in the motor quiescence phase of the interdigestive myoelectric complex (11)]. In the cutaneous signal a small sinusoidal component of about 5 cycles per minute can be seen. This component was present in 91.4% of the blocks with complete motor quiescence. By means of spectral analysis it was demonstrated that the fundamental frequency of this component and the fundamental frequency of the simultaneously derived serosal signal were always equal, which proved the gastric origin of the electrogastrogram (Figure 3). When a tachygastria (12) was present in the antrum, and ERA was absent, the cutaneous signal contained the tachygastric frequency (Figure 4). From these results we conclude that gastric ECA contributes to the electrogastrogram.

When phasic contractions and ERA occurred, the amplitude of the electrogastrographic signal increased. As illustrated in Figure 5 and 6A, the amplitude variations of the cutaneous signal often ran parallel to the amplitude variations of the "second potential" (13) derived from the distal antrum. (It should be noted here that in the canine stomach ERA does not always consist of spikes; often only second potentials are present. In this paper both second potentials without and second potentials with spikes are designated ERA.) However, as illustrated in Figure 6B, it was not possible to specify an EGG amplitude level above which contractions were always present and below which there were never contractions. At this stage we had to conclude that the electrical phenomena that accompany the phasic contractions, or the phasic contractions themselves, also contribute to the electrogastrogram.

In order to rule out the possibility that changes in the electrical impedance of the body, caused by gastric mechanical activity, play a role in the genesis of the electrogastrogram, the impedance variations of the tissue between the abdominal surface electrodes were recorded in two dogs. A 10-μA current at 1000 Hz was used, because at this frequency the impedance of the electrode-electrolyte interface is low in comparison with the impedance of the body (14). The impedance records did not show any fluctua-

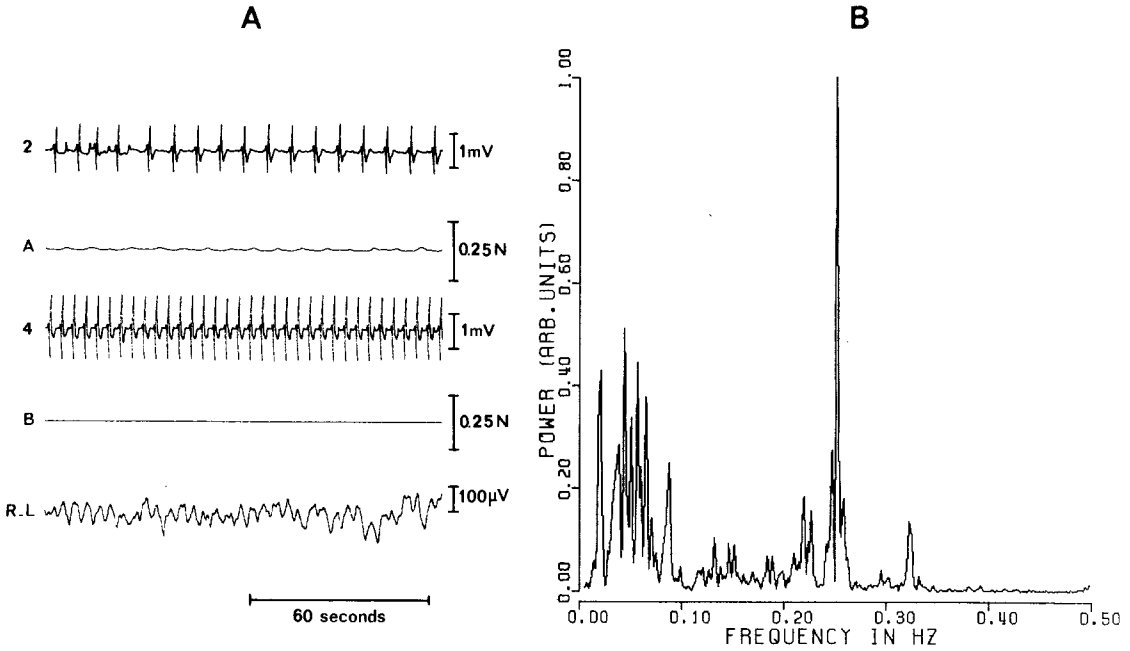

Fig 4. (A) Tachygastria recorded from serosal (2 and 4) and cutaneous (R-L) electrodes. (B) Smoothed power spectrum of the cutaneous signal shown in A. The frequency of the tachygastria is 0.25 Hz (15.06 cpm).

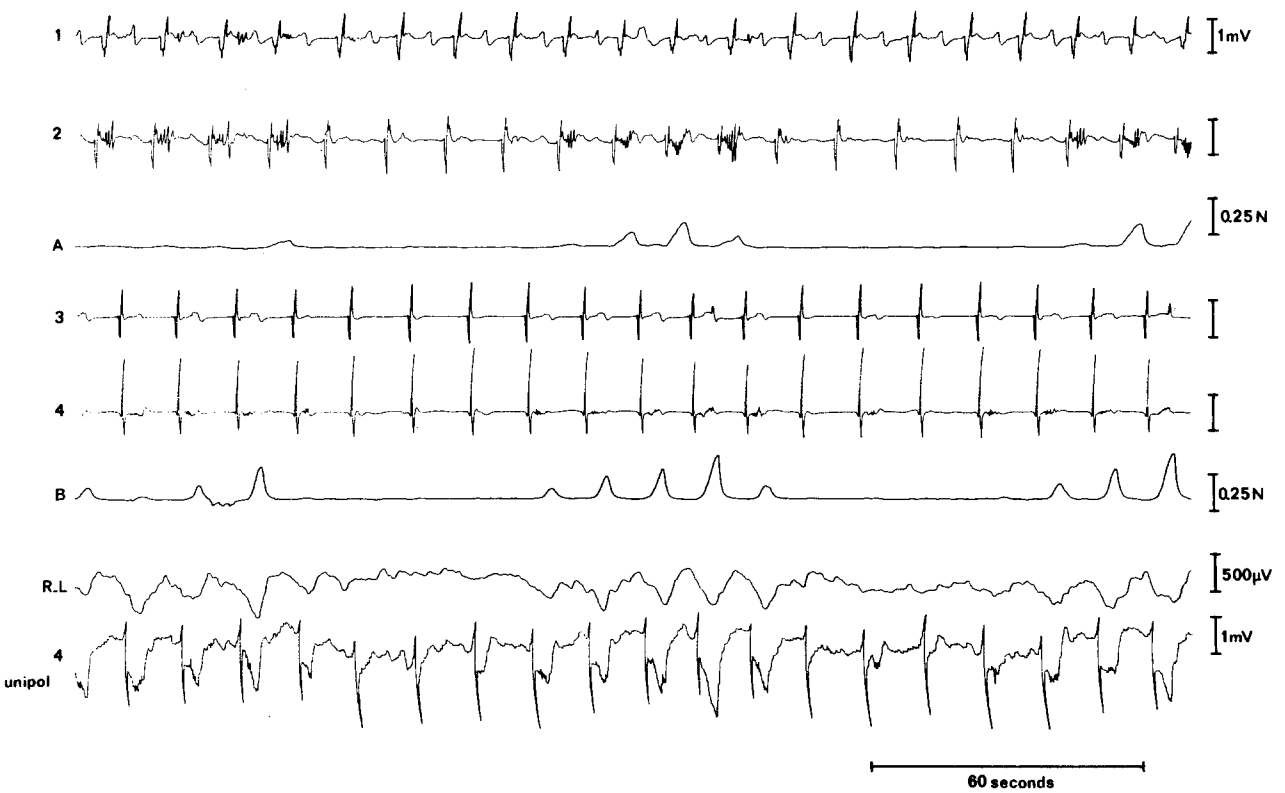

Fig 5. Recording of gastric myoelectrical and mechanical activity (bipolar serosal electrodes 1, 2, 3, and 4; strain gages A and B) and the corresponding cutaneous signal (R-L). The bottom signal was derived from electrode 4 by means of a unipolar technique (filter settings 0.025 and 15 Hz). In this signal the second potential is more easily recognized than in the bipolar signals.

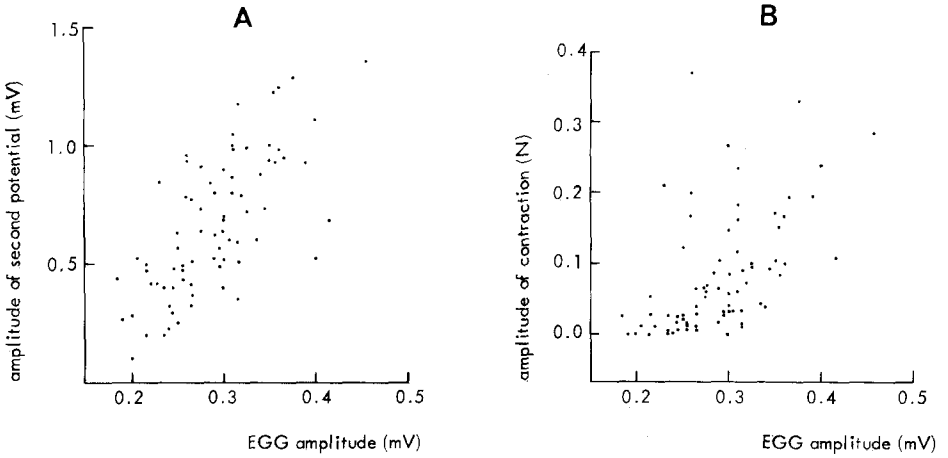

Fig 6. Example of the relation between EGG amplitude and amplitude of the second potential (A) and of the relation between EGG amplitude and contractile force (B). Amplitude of second potential and contractile force were measured from signals obtained with electrode 4 (unipolar) and force transducer B, respectively. The figure covers 80 consecutive ECA intervals (one 17.07-min block). Fasting dog, intermediate type of motor pattern.

tions corresponding to gastric contractions. The possibility that gastric contractions mechanically disturb the electrode-electrolyte interface and thus produce measurable potential variations can be ruled out by the simple observation that contractions of the stomach produced no visible movements of the surface electrodes, while relatively vigorous manipulation of the (recessed-type) electrodes produced no artifacts.

We conclude from the above that the electrogastrogram is generated by the myoelectric activity of the stomach and that both ECA and ERA are reflected in it.

DISCUSSION

The finding that the gastric frequency can be derived from the skin in the absence of phasic contractile activity is in accordance with the results of Brown et al (7), who concluded from their experiments in man that in EGG the basic electrical rhythm (ie, ECA) of the stomach is measured. However, our study shows that not only ECA, but also ERA is reflected in the electrogastrogram. In order to explain the increased amplitudes of electrogastrograms after a meal, Brown and colleagues supposed that after a meal the closer proximity of the electrodes to the distended stomach accounts for better recording conditions. Although it seems likely that variations in the position of the stomach modulate the amplitude of the electrogastrogram, this mechanism cannot be the only one involved, since we also observed increased amplitudes during isolated contractions in an empty stomach [during IDMEC phase II (11)].

Our conclusion that both ECA and ERA are reflected in the electrogastrogram explains the correlation between phasic contractions of the stomach and increased amplitudes in the electrogastrogram, as observed or postulated by most investigators in this field.

In order to obtain a better insight into the genesis of the electrogastrographic signal, dipole theory was applied to gastric electrical activity. The following description of the resulting provisional EGG model will be in qualitative terms; for a quantitative and mathematical treatment the reader is referred to the Appendix.

It is known from work with intracellular electrodes (13, 15) and with the sucrose-gap technique (16) that in antral smooth muscle there is a fast initial depolarization followed by a plateau. Spikes may occur superimposed upon the plateau. The duration and amplitude of the plateau increase with increasing contractile force, while the configuration of the initial depolarization is relatively constant (Figure 7). The initial depolarization gives rise to an ECA pulse in the extracellular recording. Spikes and repolarization manifest themselves in the extracellular recording as spikes and second potential, respectively.

In the present model initial depolarization and repolarization are represented as dipoles. The depolarization dipoles are considered to be of constant magnitude, while the magnitudes of the repolariza-

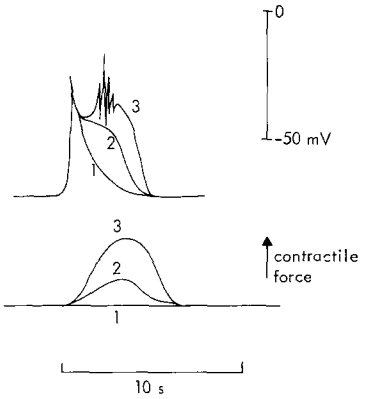

Fig 7. Intracellularly recorded electrical activity of antral smooth muscle and the corresponding mechanical activity. Stronger contractions are related to higher plateaus of longer duration. The spikes shown here on the plateau may be absent. [After Daniel (13), Papasova et al (15), and Szurszewski (16).]

tion dipoles vary with repolarization rate. The spikes, being asynchronous oscillations of the membrane potentials of individual cells, are assumed not to constitute significant dipoles.

During motor quiescence the plateau is small or absent and the rate of repolarization is low. Therefore, repolarization dipoles are thought to be absent or of low amplitude during motor quiescence; only depolarization dipoles are present. At some distance from the stomach, the slowly propagating series of depolarization dipoles is recorded as a sinusoidal signal (Figure 8A).

When contractions occur and repolarization rates are higher, repolarization dipoles are present between the depolarization dipoles. Since these give rise to potentials of opposite polarity with a phase difference of about π radians with the depolariza-

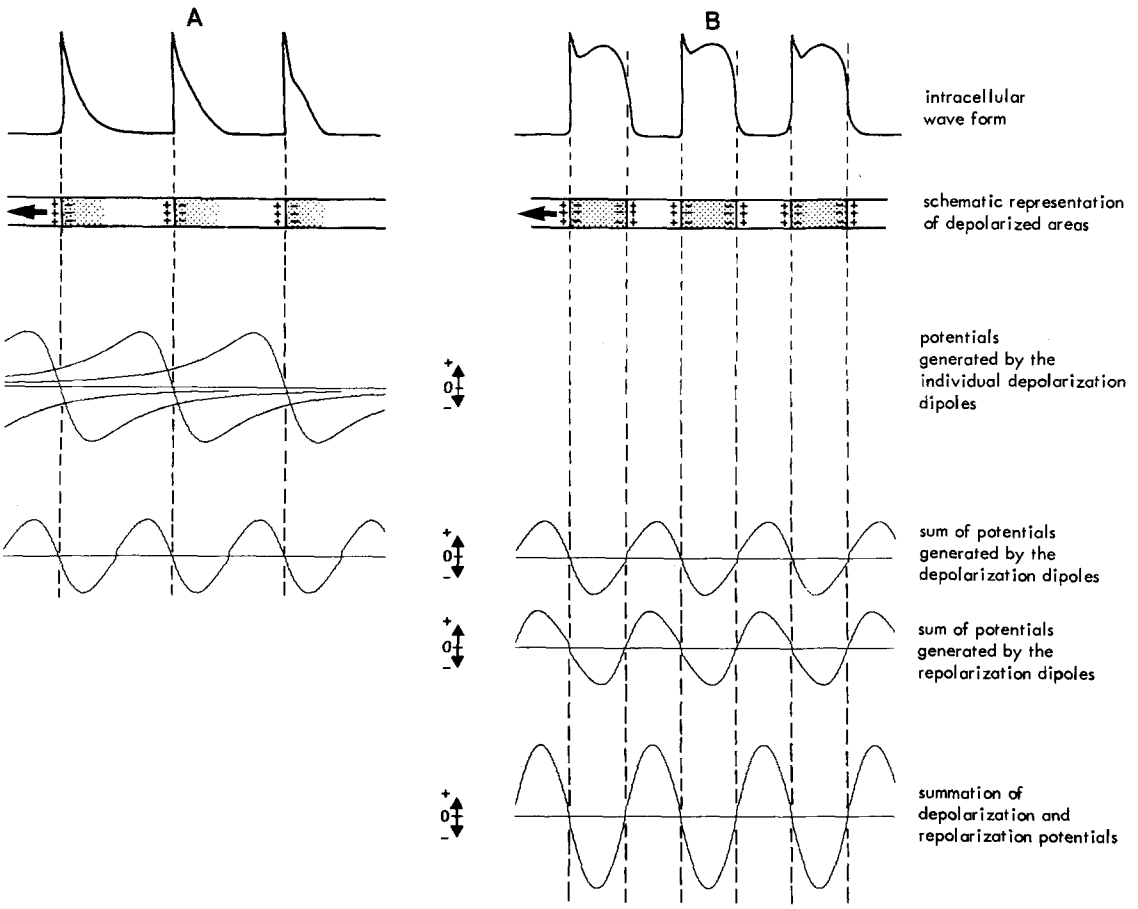

Fig 8. (A) Computer simulation of the potential variations recorded when a series of equally spaced depolarization dipoles travels slowly underneath a remote electrode, as in a mechanically inactive stomach. (B) Computed potential variations when in addition to depolarization dipoles repolarization dipoles are present, as in mechanically active stomach. (Distance from electrode to dipole axis 5 cm. For other parameters see Appendix.)

tion effects, the summation of the potentials generated by both types of dipoles yields a sinusoidal signal of increased amplitude (Figure 8B).

Although the above-described model is only a first approximation, the sinusoidal configuration of the electrogastrographic signal as well as the ERA-related amplitude changes can be understood with it.

Much more work has to be done before the electrogastrogram can be understood to the full. For instance, our data suggest that the activity of the distal antrum dominates the electrogastrogram. This could be explained by the fact that both amplitude and propagation velocity of gastric myoelectric activity increase towards the pylorus. It should be investigated, however, whether electrodes at other sites on the abdomen "see" other parts of the stomach.

Whether the electrogastrogram might eventually be used as a diagnostic tool, as has already been claimed by several authors (3, 6, 17–20), is a question that cannot be answered on the basis of the present study.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the technical assistance of Mr. J.V. de Bakker and Mr. W.H. Groeneveld and wish to thank Mr. M.A. Kentie for his constructive suggestions. The animal experiments described in this paper were carried out in cooperation with the Laboratory for Experimental Surgery of the Erasmus University Rotterdam, which is under the direction of Dr. D.L. Westbroek.

APPENDIX

In a volume conductor the potentials generated by bioelectric events can be described with the aid of dipoles. In the presented EGG model current dipoles were used, each consisting of a source of current I and a nearby sink of current I.

A current point source in a homogeneous, conducting medium produces a potential field ϕ_P in a point P:

$$\phi_P(r) = \frac{I}{4\pi\sigma} \cdot \frac{1}{r}$$

where r is the distance from P to the source and σ is the conductivity of the medium.

The potential at a point P at (x, y) produced by a source and a sink on the x axis at $(-b, 0)$ and $(b, 0)$ is

$$\phi_P(x, y) = \frac{I}{4\pi\sigma}\left(\frac{1}{\sqrt{(x+b)^2 + y^2}} - \frac{1}{\sqrt{(x-b)^2 + y^2}}\right)$$

Both depolarization and repolarization propagating along a nerve fiber or a muscle cell can be represented by a traveling current dipole. The magnitudes of sources and sinks and the source-sink distances depend on the intracellular wave form, since it can be shown that the current through the membrane is proportional to the second derivative of the membrane potential (14). Taking the proportionality factor 1, depolarization and repolarization can each be represented by a current dipole

$$i_m = h\delta(x + b) - h\delta(x - b),$$

where i_m is the current through the membrane, h is the slope of the membrane potential change, and δ is the Dirac delta function, as illustrated in Figure A-1.

The magnitude I of source and sink is proportional to h and the distance between source and sink amounts $2b$.

When the membrane potential is constant, no dipoles are present and no external field exists. All propagating membrane activities can be described either as time- or as place-dependent changes, these being related through the velocity v $(= dx/dt)$ of the propagating phenomenon.

Figure A-2 shows the potential distribution along a line parallel to the axis generated by one stationary dipole on the x axis. If the dipole is assumed to travel along the x axis, Figure A-2 shows the potential variations at a fixed point and the abscissa has the dimension of time.

In the EGG model presented in this paper the following assumptions were made: the stomach is a cylinder of infinite length; the cylinder is homogeneously filled with muscle cells; both depolarization and repolarization take place synchroneously in the radial plane; and depolarization and repolarization fronts are propagated with constant velocity.

It was further approximated that: All dipoles in a radial plane are located at the cylinder axis. It can be shown that this leads to errors smaller than 1% when the distance to the cylinder axis is more than twice the cylinder radius. Consequently, one of the features of the model is that ring-shaped deformations of the stomach (phasic contractions) hardly influence the potential field at some distance from the cylinder. With regard to the repolarization dipoles the following approximations were made: In the absence of contractions the magnitude of the repolarization dipole is zero, since the slope of repolarization is relatively small (see Figure 7, curve 1). In the presence of strong contractions the repolarization dipole is as strong as the depolarization dipole (but of opposite polarity), since in that case the slope of repolarization is almost as steep as the depolarization slope (Figure 7, curve 3).

With these approximations and assumptions the potential at a point $P(x, y)$ generated by one depolarization and one repolarization front propagating over the stomach is:

$$\phi_P(x, y) = \frac{1}{4\pi\sigma}\left[I\left(\frac{1}{\sqrt{(x - x_D + b)^2 + y^2}} - \frac{1}{\sqrt{(x - x_D - b)^2 + y^2}}\right) - \alpha I\left(\frac{1}{\sqrt{(x - x_R + b)^2 + y^2}} - \frac{1}{\sqrt{(x - x_R - b)^2 + y^2}}\right)\right]$$

where $(x_D, 0)$ is the center of the depolarization dipole, $(x_R, 0)$ is the center of the repolarization dipole, $\alpha = 0$ for absence of phasic contractions, $\alpha = 1$ for presence of strong phasic contractions.

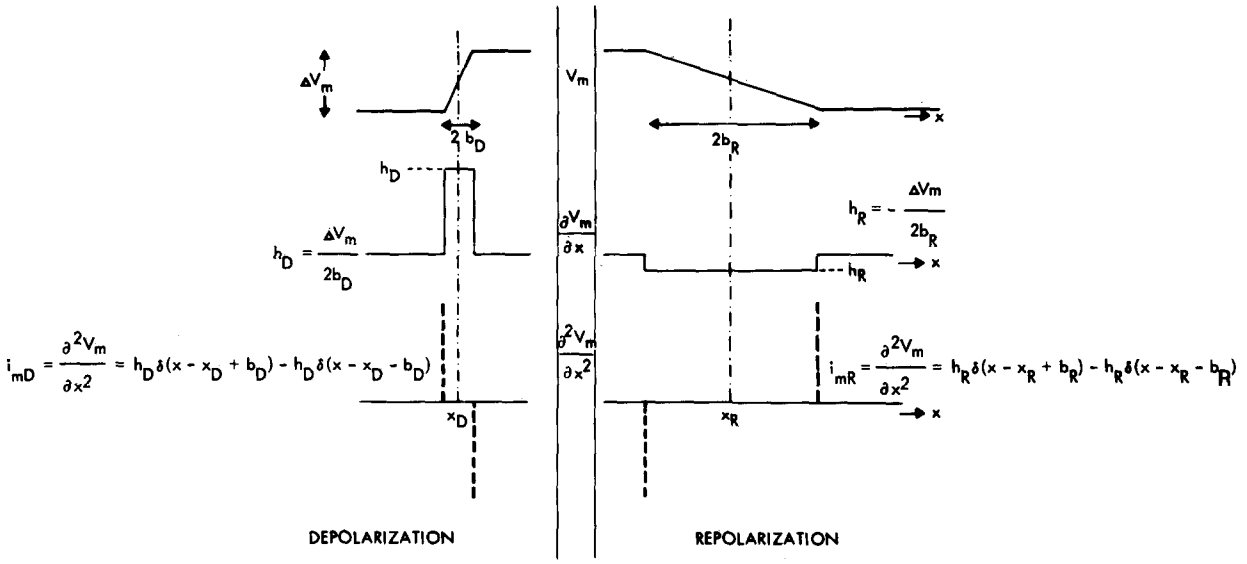

Fig A-1. Construction of depolarization and repolarization dipoles from a schematic intracellular waveform. V_m is the membrane potential, for further explanation see text.

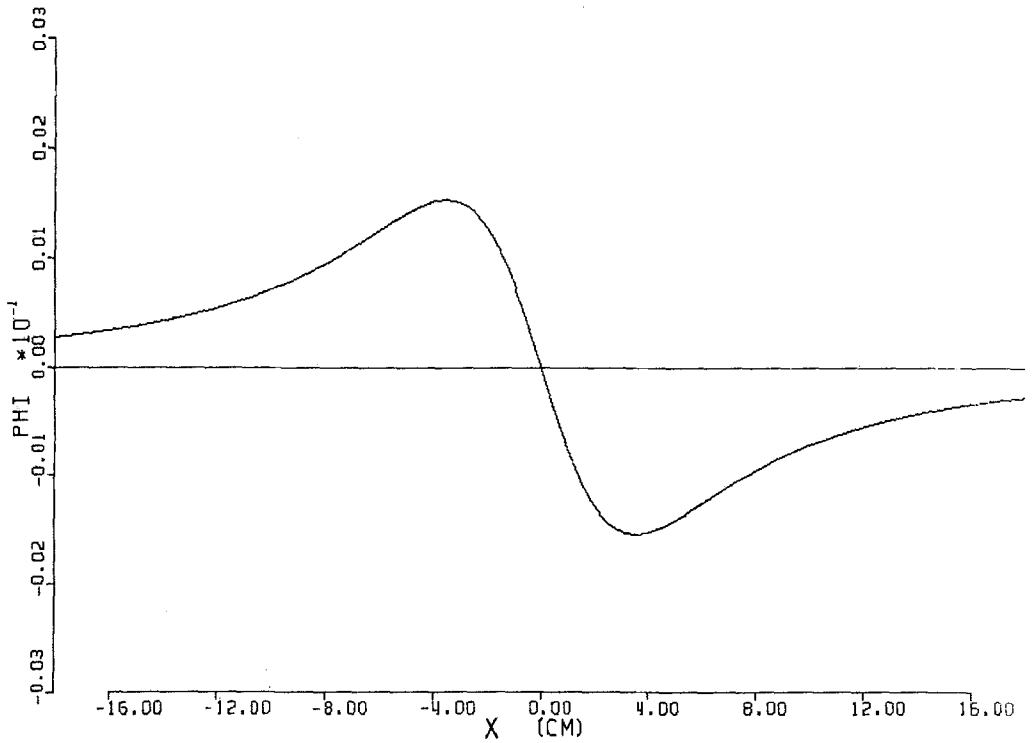

Fig A-2. Potential ϕ at a line parallel to the x axis (y = 5 cm) generated by a stationary current dipole with source at $(-b, 0)$ and sink at $(b, 0)$ (b = 0.05 cm). Ordinate: potential ϕ in units $I/4\pi\sigma$.

The results of the model for a series of consecutive depolarization and repolarization dipoles are shown in Figure 8.

For the propagation velocity of the dipoles 1 cm/sec was chosen and for the time interval between the depolarization dipoles 12.5 sec. The resulting distances between consecutive depolarization dipoles is 12.5 cm. Based on an approximated slope of depolarization of 1 V/cm and a membrane potential change of 100 mV, the distance between source and sink of one dipole was fixed at 0.1 cm.

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