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Computer simulation of the effect of changing abdominal thickness on the electrogastrogram

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Abstract

The effect of different abdominal thickness on cutaneous recordings of gastric electrical activity (GEA) known as electrogastrograms (EGG) have not been adequately studied. The stomach was represented as a truncated conoid in spherical system of coordinates. Gastric electrical field was modelled using previously described methodology. Electrical voltages were calculated in simulated standard cutaneous recordings. The effect of increased thickness of the abdominal layers was quantitatively examined. Changes of the thickness of the abdominal layers significantly affected signal-to-noise ratio of EGG. When the critical abdominal thickness of 7 cm was exceeded, EGGs were quantified as abnormal although the internal GEA was normal. Computer modelling indicated that changeable abdominal thickness caused by the abdominal layers separating the stomach from the recording electrodes significantly influence the EGG recordings even if the layers are homogeneous. © 1998 IPEM. Published by Elsevier Science Ltd

Keywords: Electrogastrography; Validity; Computer modelling

Abbreviations

cpm	cycles per minute
EGG	electrogastrography, electrogastrogram
EKG	electrocardiography, electrocardiogram
FHT	Fast Hartley transform
GEA	gastric electrical activity
MF	mean frequency
pdf	probability density function
SD	standard deviation
T–F	time–frequency

1. Introduction

Cutaneous recording of gastric electrical activity (GEA), a technique called electrogastrography (EGG), has been known for more than 70 years but still its reliability remains questionable. [1–3] Previous studies described some of the external factors that influence this reliability [1–4] and suggested quantitative methodology for EGG assessment. [4] The finding that body mass index influences the EGG validity was particularly interesting. [3] However, little has been done to investigate the possible reasons for this phenomenon. Recently, the effects of abdominal layers on cutaneous electric potentials and magnetic fields from gastrointestinal sources were examined using computer modelling. [5] In the present study we applied our previously developed modelling and quantification techniques [4,6] to examine the effect of the thickness of the abdominal layers on the electrogastrogram.

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2. Methods

2.1. Synthesizing simulated EGG signals

In the conoidal dipole model of GEA the stomach was represented as a truncated conoid in an infinite homogeneous medium and spherical system of coordinates. The equation for the electrical potential measured at a point located anywhere in the vicinity of the truncated conoid was given with: [6]

$$V_Q = [1/4\pi\epsilon]\int_S [(\mathbf{D}.\rho)/\rho^3]\,\mathrm{d}S \quad (1)$$

where S is the area of the δ-wide band (or ring) representing the polarized cells, **D** is the vector of the dipole density of that band, and ρ is the vector distance between the point of interest and the infinitesimal area segment dS, situated on the polarized band (Fig. 1).

2.2. Changes in the thickness of abdominal layers

Even if we assume that the abdominal layers are an infinite homogeneous medium, changes in tissue tickness result in changes of one important parameter that participated in equation [1]—the vector distance ρ between the point of interest and the infinitesimal area segment dS, situated on the polarized band. We assumed that the effects related to spatial integration caused by the abdominal layers regarded as a non-homogeneous volume conductor are important [5] but concentrated at quantifying the impact of the change of the distance between the source of the electrical field (the stomach) and the measuring point. Four distances were studied representing different abdominal thicknesses: 3, 5, 7 and 9 cm.

When simulating EGG measurements one additional integration is needed which would represent the superposition of the electrical voltages recorded from each and every point of the active electrode surface area S_E:

$$V_{\mathrm{EGG}} = \left[\int_{S_E} V_S\,\mathrm{d}S_E\right]/S_E \quad (2)$$

In real-life studies we use standard neonatal EKG (Neotrode, Medtronic, Haverhill, Mass.) electrodes to record bipolar EGG from all subjects (including dogs). [1,4] These electrodes have a diameter of 26 mm (the active surface area is a circle), a value that we utilized in the present study. We have previously described how to solve Eq. (1) for a stomach with normal dimensions. [6] In the present study our next step was to quantitatively introduce the effect of changed abdominal thickness on the voltage calculated in Eq. (1) and subsequently, to describe the transformation of this newly obtained voltage after the second integration [Eq. (2)].

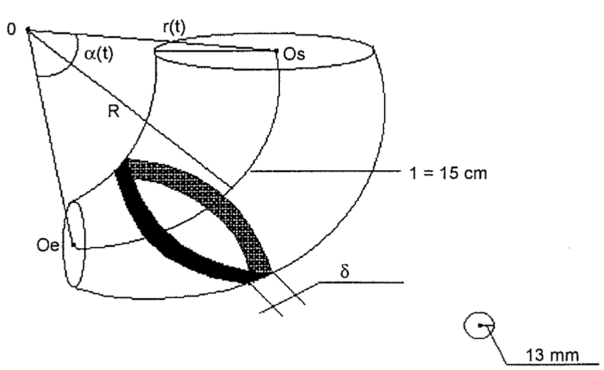

Fig. 1. Distal stomach was modelled by a truncated conoid in spherical system of coordinates. The radius of the distal electrode (below, right) was 13 mm.

2.3. Signal processing

Simulated EGGs were synthesized for 1 h. The recordings, contaminated with 0.2 mV (peak-to-peak) white noise, were filtered with frequency sampling digital bandpass filter [7] in the range of 0.02–0.1 Hz (1.2–6.0 cpm). After filtering a new sampling frequency of 2 Hz was introduced. The recordings were subjected to 512-point Fast Hartley Transform (FHT [8]) and three-dimensional representations of running spectrum analysis [9] were obtained. The dominant peak of each successive spectrum was normalized to 100% and was represented as a point in the time–frequency (T–F) plot [4] of each separate EGG channel. The points that build up the T–F plot were called mean frequency (MF) points.

2.4. Quantitative validation of the simulated electrogastrograms

In a previous study [4] the following criteria for EGG normality were introduced for signals recorded for 1 h and processed at 4.27-min (256-s) intervals

1. The mean value of all MF points for a given EGG channel lay between 2.5 and 3.75 cpm.
2. For an EGG channel to be considered stable, standard deviations of its MF points had to be < 0.450 cpm.
3. Probability density functions (pdf) of the MF points of the stable channels were bell-shaped indicating normal distribution.

Simulated GEA signals were obtained and processed under similar conditions from setups with gradually incresing abdominal thickness. The signals were obtained initially without the presence of any noise. The impact of 0.2 mV (peak-to-peak) random noise on the validity of EGGs obtained after manipulating the abdominal thickness was examined.

3. Results

3.1. Amplitude changes in EGG

The amplitude values from simulated EGG obtained with each of the 4 vector distances ρ were evaluated

Table 1
Amplitude changes in cutaneous EGG related to increased distance (abdominal thickness) between the abdominal electrode and the stomach

Abdominal thickness (cm)	3	5	7	9
Amplitude of simulated EGG (peak-to-peak, mV)	1.6	0.47	0.12	0.03

Table 2
Changes in the standard deviations of the mean frequency points calculated from a simulated signals obtained with different abdominal thicknesses and contaminated with 0.2 mV (peak-to-peak) white noise

Abdominal thickness (cm)	3	5	7	9
Standard deviation (cpm)	0.01	0.22	0.47	0.53

(Table 1). Tendency for significant non-linear decrement of the EGG amplitude was noted associated with the increment in the thickness of the abdominal layers. The greatest distance of 9 cm resulted in more than 98% decrement of the EGG amplitude compared to the smallest distance of 3 cm.

3.2. *EGG deterioration in white noise environment*

Without the presence of noise, frequency of EGG reflected correctly the frequency of normal, coupled internal GEA regardless of the increments of the distance between the actual electrical event in the stomach and the abdominal recording point and the reductions of EGG amplitude associated with these increments. The ability to recognize correctly the EGG frequency was limited only by the bit resolution of the computer on which the calculations were performed. When contaminated with 0.2 mV (peak-to-peak) of random noise, however, the EGG signals showed a clear tendency towards increasing the SD of the MF points (Table 2, Fig. 2) when increasing the abdominal thickness.

Probability density functions calculated from the MF values of simulated EGGs recorded from stomach models with increasing distances from the source of the electrical field showed clear tendency to lose their normal distribution, gradually turning the internally normal and coupled gastric electrical signals into abnormal EGG when the distance was > 7 cm (Fig. 3).

4. Discussion

These computer simulations clearly indicate that thickness of the abdominal layers might have a profound effect on EGG just because of the change in the distance between the source of the electric field (the stomach) and the measuring electrode. If all other conditions were kept the same, increased thickness of the abdominal layers influenced negatively signal-to-noise ratio of cutaneously recorded signals to a point of quantitatively assessing the latter as abnormal without an actual electrical abnormality being present. The resolution was further affected by the integration related to the active electrode surface area of the cutaneous electrodes. In fact, we would speculate that the 3rd and 4th order of the fall-off in signal amplitude reported in Table 1 of this study could be related the surface electrode integration.

The effects related to spatial integration in a volume conductor and the effects occurring on the boundary between the skin and the air would probably also worsen the overall picture since they would affect both the resolution and the power of the cutaneous signal and also introduce more nonlinear changes in the cutaneous signal [5].

5. Conclusions

Our study suggests that the variability of the thickness of the abdominal layers separating the stomach from the abdomen might have a substantial impact on the validity

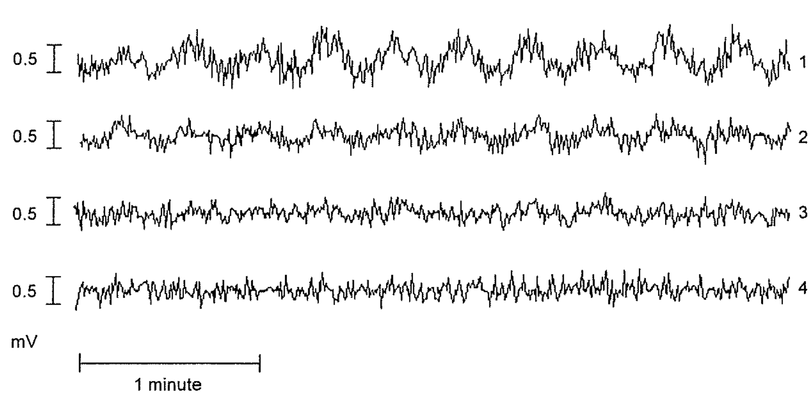

Fig. 2. Gradual deterioration of EGG signals with the change in the abdominal thickness from 3 cm (Channel 1) to 9 cm (Channel 4) with a step of 2 cm. The level of white noise was kept at 0.2 mV in all tracings.

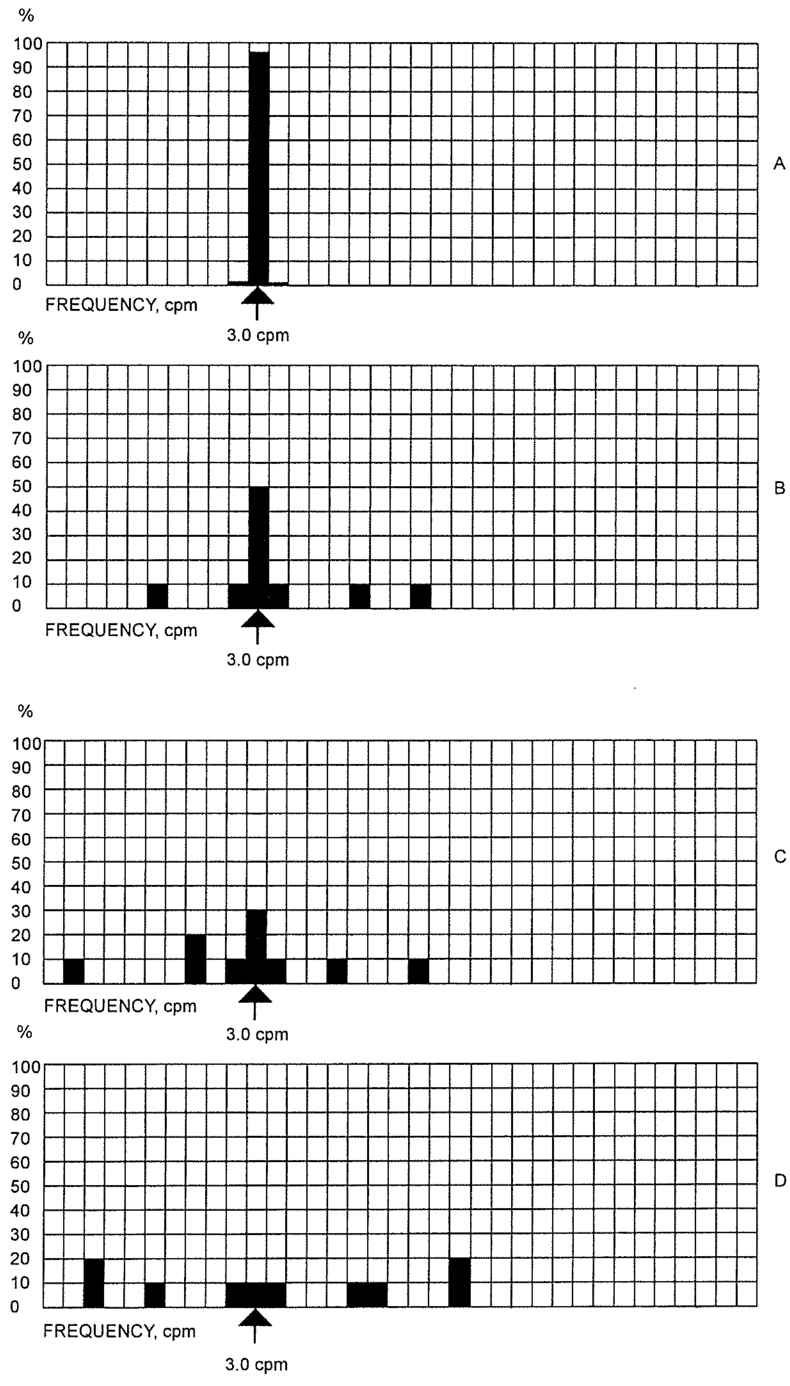

Fig. 3. Probability density functions of the mean-frequency points obtained after gradual change in the abdominal thickness from 3 cm (A) to 9 cm (D) with a step of 2 cm.

of EGG. These findings might be important when evaluating EGG from obese patients.

References

[1] Mintchev MP, Bowes KL. Accuracy of cutaneous recordings of gastric electrical activity. Gastroenterology 1993;104:1273–80.

[2] Pfaffenbach B, Wedmann B, Adamek RJ, Wegener M. The significance of electrogastrographically determined amplitudes—is there a correlation to sonographically measured antral mechanical contractions? Z. Gastroenterol. 1995;33:103–7.

[3] Smout AJ, Jebbink HJ, Akkermans LM, Bruijs PP. Role of electrogastrography and gastric impedance measurements in evaluation of gastric emptying and motility. Digestive Diseases and Science 1994;39(12Suppl.):110S–3S.

[4] Mintchev MP, Bowes KL. Extracting quantitative information

from digital electrogastrograms. Med. Biol. Eng. and Comput. 1996;34:244–8.

[5] Bradshaw LA, Wiskwo JP, Richards WO. A comparison of the effects of abdominal layers on external electric potentials and magnetic fields from gastrointestinal sources. Digestive Diseases and Sciences 1996;41(9):1884.

[6] Mintchev MP, Bowes KL. Conoidal dipole model of electrical field produced by the human stomach. Med. Biol. Eng. and Comput. 1995;33:179–84.

[7] Oppenheim, AV, Schafer, RW, Digital signal processing. Reston, Va: Prentice–Hall, 1984.

[8] Bracewell, RN, The Hartley transform. New York: Oxford University Press, 1986.

[9] Van Der Schee EJ, Grashuis JL. Running spectrum analysis as an aid in the representation and interpretation of electrogastrographic signals. Med. Biol. Eng. and Comput. 1975;13:97–102.