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NON-INVASIVE ELECTROGASTROGRAPHY

PART 2

HUMAN ELECTROGASTROGRAM

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ABSTRACT

The electrical activity of human stomach muscle wall - electrogastrogram (EGG), was led off by surface (cutaneous) electrodes placed on the abdominal wall and recorded on an electrogastrograph. A method for complete elimination of the cardiac artefact was elaborated and successfully implemented. It consists of a preliminary elimination of the QRS complex, based on its higher amplitude and slope. The eliminated intervals were replaced by linear segments. A subsequent low-pass filtering allowed to obtain a high quality EGG signal. The electrical activity of the stomach of healthy volunteers was characterized by waves with a frequency of 3.35 ± 0.09 cpm during the quiescent periods and 2.99 ± 0.14 cpm during the activity periods of the migrating myoelectrical complex (MMC). Bearing in mind the correlation between the bursts of spike potentials with the slow waves in the dog EGMG and the high-amplitude waves, characterizing the periods of activity in the dog EGG, we can better differentiate the periods of quiescence and activity by the amplitude of the waves. The wave amplitude during periods of quiescence was 81.13 ± 20.61 μV, significantly different from the wave amplitude during periods of activity being 164.74 ± 43.34 μV (n=7). Thus with this method in visual inspection it is possible to identify MMC of the human stomach by the changes in the amplitude of the waves in the EGG.

KEY WORDS: *stomach, electrical activity, cutaneous electrodes, EGG, visual interpretation, human gastric MMC.*

INTRODUCTION

Electrogastrography (EGG) is a non-invasive method for recording the electrical activity of the gastric muscle wall. This method could be very useful for the diagnosis of gastric motility disorders but it is still at experimental level (Chen & McCallum, 1991 a) mainly because of the relatively low quality of the EGG records impaired by artifacts (cardiac activity, respiration, small intestinal activity, movements, skin-electrode noise, etc.). This requires computer processing of the data in order to separate the gastric signals from the artifacts (Abell & Malagelada, 1988). However, "computer analysis ... is somewhat risky for its potential to *create* nonexistent data" (Abell & Malagelada, 1988). The combination of clear recordings amenable to visual inspection and computer-assisted analysis would offer the best of all possibilities (Abell & Malagelada, 1988).

The purpose of this work was to obtain very high quality EGG recordings intended for assessment of the changes in stomach electrical activity in order to

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characterize the periods of quiescence and activity of the migrating myoelectrical complex (MMC) and to show the end of the evacuation of the gastric contents.

METHODS

Investigations were made on 26 healthy volunteers – 14 females and 12 males, mean aged 32.4 (17 - 58) years, without any gastrointestinal complaints. The procedure of the investigation was explained and their signed consent was obtained. The persons were lying in supine position, kindly requested not to move, without speaking.

The electrogastrogram (EGG) was recorded by cutaneous electrodes on the abdominal wall (Fig. 1). The position of the active electrodes was as follows: electrode 2 was placed just under the left lower rib, on the line between the nipple and the navel; electrode 1 - 3 cm above it, on the chest; 3 - on the line between 2 and navel; 4 - under the right lower rib, opposite 2. The reference electrode (R) was placed to the right of the navel. Conventional type disposable pre-jelled stick-on electrocardiographic electrodes were used.

The records were made on an 2-channel electrogastrograph, designed by us. A method for complete elimination of the cardiac artefact was elaborated and successfully implemented. It consists of a preliminary elimination of the QRS complex, based on its higher amplitude and slope. The eliminated intervals were replaced by linear segments. A subsequent low-pass filtering allowed to obtain high quality EGG signals. The input signals were analog-to-digital converted with a relatively high sampling rate of 200 Hz allowing adequate digital acquisition of both electrocardiogram (ECG) and EGG signals. The residual mains interference was additionally removed using an artifact subtraction procedure in real time (Christov & Dotsinsky, 1988; Levkov *et al.*, 1984)

The total elimination of the heart electrical activity artifacts began with the identification of high and steep waves. These were usually the QRS complexes but might be large and steep T waves too. Their participation in direct averaging of the signal could be disturbing, because the high amplitudes will not be suppressed radically, despite the relatively good frequency separation from the EGG signals. Therefore, these waves were cancelled and substituted by linear segments. Then a digital averaging filter was applied with a selectable cut off frequency of 0.2 or 0.4 Hz. Thus the electrocardiogram signals were removed entirely.

A large number of electrocardiograms were investigated to define the appropriate criteria for identification of the high and/or steep waves. The results pointed out that the beginning of these waves must be set when the slope of the signal exceeded the level of 2.5 μV/ms. The end of the same waves was detected by a more sophisticated algorithm because of the risk of false detection in larger and longer elevated or depressed quasi horizontal ST segments. An interval with a slope continuously lower than 2.5 μV/ms during 250 ms was searched for. Once this requirement was met, the end of the high and/or steep wave was marked off 250 ms back on the time scale.

Investigations were made on 8 - 10 hours fasting persons: i) after 2 - 3 hours of recording the volunteers were given standardized meal; 20 - 30 min later the investigation continued for 40 - 60 min. ii) after 1-hour of recording the same type of food was given to the volunteers, the recording began 20 - 30 min later and lasted 2 - 3 hours.

The standardized meal consisted of two sandwiches with ham or sausages, a cup of fruit juice and coffee (proteins - 47 g, 192,7 Kcal; fats - 3,4 g, 31,62 Kcal; carbohydrates - 115 g, 471,5 Kcal; total - 695,82 Kcal).

The amplitude and the frequency of the gastric waves in the EGG was measured in selected intervals: i) low-amplitude waves ii) high-amplitude waves; iii) waves 20 - 30 min after feeding. The amplitude of the waves was measured in mm and transformed in μV. The data were statistically processed and the means ± SEM were calculated. The statistical significance of the differences between the slow wave frequency and amplitude in the groups was shown using the Student's *t*-test

RESULTS

Waves with a frequency of about 3 cpm were obtained in all recordings from fasting volunteers. In 8 of the cases highest amplitude signals were led off with a position of the two active electrodes along the antral axis [combinations 1 - 2 or 2 - 3 (Fig. 1)]. In 16 cases however the higher wave amplitudes were obtained by 1 - 4 or 2 - 4 and in 2 studies - with 3 - 4 leads.

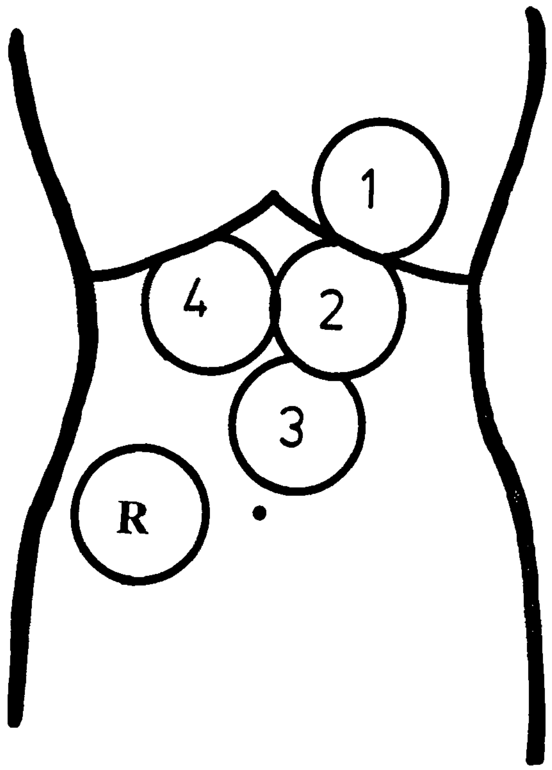

Fig. 1. SCHEME OF THE POSITION OF THE ELECTRODES ON THE ABDOMINAL WALL.

Periods with relatively low-amplitude waves, lasting about 20 - 30 min were observed in the continuous records (Fig. 2A). We measured the amplitude of 100 well expressed waves from the records of 7 persons where the mean value and SEM were 81.13 ± 20.61 μV. (Table 1).

After these periods waves with higher amplitude compared to that of the former ones began to appear in the EGG and they characterized other periods - of gastric activity (Fig. 2B). The mean amplitude and SEM of these waves were 164.74 ± 43.34 μV (n=7) (Table 1).

The statistical processing showed a significant difference between the amplitudes of the waves in these two cases (Student's *t*-test $p < 0.05$). In some studies there was an evident transition from high-amplitude to low-amplitude waves (Fig. 2C). In other cases, e.g. the one of Figure 3A,B, the amplitude of the slow waves was lower compared with the one in Figure 2A,B. The transition from low-amplitude to high-amplitude slow waves was also evident (Fig. 3C). It seems that the low amplitude waves characterized the period of quiescence, while the high-amplitude waves expressed the period of activity of the MMC. Usually the transition from one period to another was more gradual compared to that in Figures

Table 1. Frequency and Amplitude of the Slow waves in the EGG of healthy volunteers.

Name	Fasting state				Name	After feeding					
	Low-ampl. waves		High-ampl. waves			Waves 20-40 min after feeding		Low-ampl. waves		High-ampl. waves	
	υ	A μv	υ	A μv		υ	A μv	υ	A μv	υ	A μv
1.K.S.	3,283	58,44	2,955	154,38	M.K.	3,291	186,25	3,545	98,13	3,579	142,33
2.T.S.	3,331	106,46	2,837	174,16	C.K.	3,318	273,43	3,398	86,08	3,181	181,25
3.S.W.	3,358	112,75	3,269	231,38	K.S.	3,135	316,80	4,12	83,75	3,376	176,25
4.I.R.	3,318	72,91	2,835	145	I.R.	3,228	259,88	3,378	103,13	3,284	155,36
5.P.I.	3,209	93,75	2,932	216,88	M.K.	3,513	191,88	2,929	131,25	2,749	159,59
6.I.R.	3,493	59,59	3,027	116,88	I.R.	3,235	367,5	3,597	91,25	3,172	171,5
7.A.A.	3,451	64	3,1	114,5	A.A.	2,909	250	3,05	93,75	2,854	148,66
Mean value	3,349	81,11	2,994	164,74		3,189	263,66	3,407	98,093	3,139	162,13
SEM	0,09	21,182	0,143	42,358		0,369	14,93	0,277	13,515	0,182	59,818

υ - Frequency of slow waves per min
A - Amplitude in μV

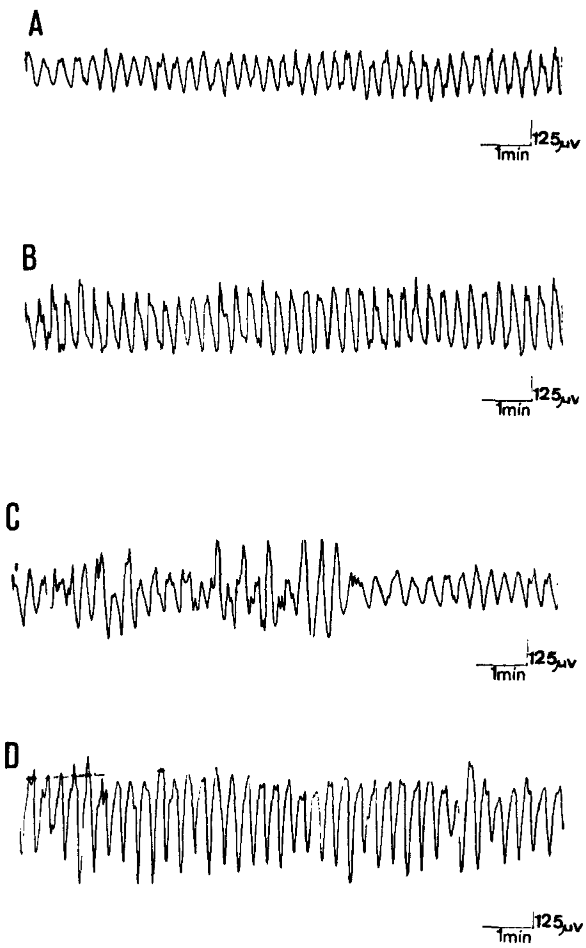

Fig. 2. HUMAN ELECTROGASTROGRAM (EGG), CHARACTERIZED BY WAVES WITH A FREQUENCY ABOUT 3 CPM.
A: low amplitude waves corresponding to the quiescent - period of MMC (migrating myoelectric complex);
B: waves with higher amplitude compared to that in A. They represent the active period of MMC;
C: transition from an active to a quiescent period;
D: gastric slow waves after feeding.

2 and 3. Such a transition was observed during 3 - 5 min and seemed like II or IV phase of MMC.

After feeding (20 - 30 min) the amplitude of the waves in the EGG increased significantly (Fig. 2D). The mean value of the wave amplitude reached 263 ± 59.82 µV (Table 1). Continuous records showed that about 40 min after feeding the amplitude decreased for several minutes, after that gradually increased and was modulated in this manner during about two hours (Fig. 4C). After that low-amplitude waves appeared again. Statistically proven differences were found between the low-amplitude wave frequencies - 3.349 ± 0.09 cpm and the high-amplitude waves frequencies - 2.994 ± 0.14 cpm.

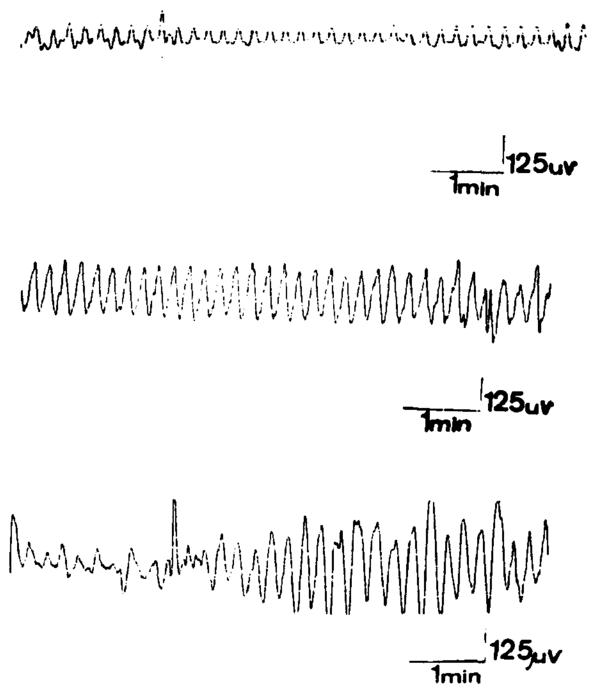

Fig. 3. ELECTROGASTROGRAM OF ANOTHER VOLUNTEER. Descriptions of A,B, – as in Fig.2. C – transition from low-amplitude to high-amplitude waves.

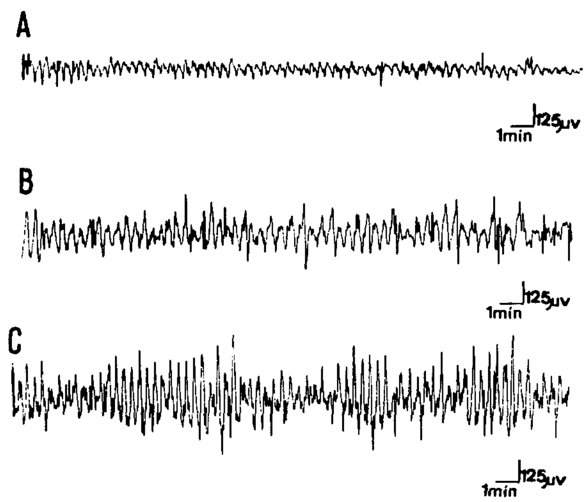

Fig. 4. ELECTROGASTROGRAM AFTER FEEDING.
A: background low-amplitude waves in fasting state;
B: background high-amplitude waves;
C: wave-like modulation of the slow wave amplitude 40 min after feeding.

DISCUSSION

The method presented made possible to obtain high quality recordings of EGG without artifacts of cardiac activity and mains interferences. The records of the EGG signals permitted to directly identify two kinds of waves by their amplitude, i.e. by the intensity of the electrical signal. The low-amplitude waves (81 ± 20 μV) evidently correspond to the low-amplitude waves in dog EGG. It was previously shown that these low-amplitude waves are related to the slow potentials in the dog electrogastromyogram (EGMG) (Atanassova *et al.*, 1995). Thus they characterize the period of quiescence in the MMC. The high-amplitude waves, as significantly more intensive electrical signals (164 ± 43 μV) correspond to the high-amplitude waves found in dog EGG (Atanassova *et al.*, 1995), i.e. to the slow potentials with spike potentials in a dog EGMG. There is a correlation between the appearance of spike bursts and the increase of the wave amplitude in the EGMG (Atanassova *et al.*, 1995). Besides, the larger the number of spikes in a group and the higher their frequency, the higher the amplitude of the waves in the EGG.

Our findings are in agreement with data of other authors showing association between the amplitude increase in the human EGG and the presence of spike activity established by mucosal electrodes (Hamilton *et al.*, 1986) and between the increase of the power of the gastric frequency and the increase of the motor activity studied by pressure records (Van der Shee & Grashuis, 1983). Thus sequences of high-amplitude waves in our long records could characterize the activity period of MMC. Four phases are known of MMC, three of them connected with the activity period (Carlson *et al.*, 1972). In fact it is difficult to discriminate between II and IV phase of MMC in the human EGG. In some cases the transition from one period to another was gradual, in others - more evident. These differences are known in the literature (Geldof *et al.*, 1986). The periods of quiescence or activity could also be proved by the difference in the slow wave frequency - 3.349 ± 0.09 cpm and 2.994 ± 0.14 cpm respectively. Such a relation between the duration of the electrical control activity (ECA) intervals and the high power low-frequency components during the activity front of MMC was already shown (Van der Schee & Grashuis, 1983). The relatively low frequency of the waves could be related to the more powerful contractions of the gastric muscle wall and could be used to determine the MMC activity front.

The increase of the slow wave amplitude after feeding confirms the data in the literature (Brown *et al.*, 1985; Chen & McCallum, 1990; Chen *et al.*, 1990; Desvaranness *et al.*, 1993). We expressed quantitatively the amplitude increase. The mean value of the slow wave amplitude 20 - 40 min after feeding was 263 ± 59 μV, significantly different, compared to that of high-amplitude slow waves in fasting state. (164 ± 43 μV). The significant increase of the wave amplitude after feeding shows the increase of the gastric muscle contractions as did the temporarily increased waves after sham feeding (Stern *et al.*, 1989). The fact that 30 - 40 min after feeding the slow wave amplitude decreased and showed modulations might be connected with the partial evacuation of the gastric contents, with the decrease of the gastric distension (Brown *et al.*, 1985). The modulations of the slow waves after feeding evidently correspond to the fed pattern electrical activity (Code & Marlett, 1975). The end of the modulations of the wave amplitude after feeding after about 2 hours probably shows the end of the gastric evacuation (Jones & Jones, 1985). The appearance of low-amplitude slow waves would show the beginning of the quiescent period of MMC. We hope to be able to determine the changes in the time of evacuation of standardized meals in patients with motility disturbances.

It was recommended to made bipolar recordings with electrodes along the longitudinal gastric axis (Mirizzi & Scafoglieri, 1983; Chen & McCallum, 1991b). One of the earlier investigations was made by pairs of electrodes in horizontal direction (Brown *et al.*, 1985). We made good recordings with one active electrode on the antral axis and another disposed under the right lower rib (combinations 1 - 4, 2 - 4, 3 - 4, Fig. 1).

Using our adequate method we recorded very high quality EGG which gives reliable information about the functional state of the human gastric muscle wall in fasting and fed states. The quiescent and activity periods of MMC could be identify by the difference in the amplitude of the slow waves, completed by the difference in the slow wave frequency. The computer analysis of such good signals would bring more useful information.

Further the method is applicable in routine clinical investigations of gastric motility disturbances, in spite of scepticism expressed by some authors (Mintchev *et al.* 1993).

RESUME

L'activité électrique de la paroi musculaire gastrique chez l'homme a été dérivée par des électrodes cutanées, placées sur l'abdomen (électrogastrogramme EGG) et enregistrée par un électrogastrographe. Une méthode éliminant complètement l'artéfact de l'activité électrique du coeur a été élaborée et appliquée avec succès. Elle consiste en une élimination préalable du complexe QRS, basée sur leur amplitude et pente élevées. Les intervalles éliminés ont été remplacés par des segments linéaires. Une filtration passe-bas ultérieure a permis d'obtenir un signal EGG de haute qualité. L'EGG de volontaires normaux était caractérisé par des ondes à frequence 3.35 ± 0.9 cpm pendant les périodes de repos et à 2.99 ± 0.14 cpm pendant des périodes d'activité. En tenant compte de la corrélation établie chez le chien entre les trains de potentiels de pointe de l'EGMG d'une part, et les ondes aux amplitudes plus élevées caractérisant les périodes d'activité de MMC d'autre part, nous avons mieux réussi à différencier les périodes de repos et d'activité par les amplitudes des ondes de l'EGG. Les amplitudes pendant les périodes de repos étaient de 81 ± 20.6 μV, différant d'une manière statistiquement significative ($p<0.05$) des amplitudes des ondes pendant les périodes d'activité, qui était de 165 ± 43 μV (n=7). De cette manière, même une inspection visuelle a permis d'identifier les MMC de l'estomac chez l'homme par des changements des amplitudes des ondes de l'EGG.

MOTS CLEF: estomac - activité électrique - EGG inspection visuelle - human MMC

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