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Discrete Laplacian Recordings of the Electroenterogram from Abdominal Surface in Humans

Gema Prats-Boluda, José L. Martinez-de-Juan, Javier Garcia-Casado, José L. Guardiola, José L. Ponce

***Abstract*—The first aim of this study was to obtain the discrete laplacian of the myoelectric small intestine signal (electroenterogram, EEnG) from bipolar recordings on the abdominal surface in humans. In addition, the objective was to identify the slow wave (SW) component of the EEnG in the estimated laplacian, as well as to compare this signal with the bipolar surface recordings. It was carried out 8 recording sessions in 6 healthy volunteers. The discrete laplacian of the surface potential was performed using Hjorth's laplacian estimation method. In order to identify the SW component of the EEnG, an adaptive filter, which removes breath interference from abdominal surface recordings, was designed. After that, periodograms and their dominant frequency were obtained. The results show that this frequency, in all surface recording channels and in their corresponding laplacian, ranges from 0.12 to 0.16 Hz (7.3 to 9.8 cycles per minute) inside of the SW frequency range, whereas the frequencies of the respiration ranges from 0.21 to 0.31 Hz (12.9-18.4 cpm). Furthermore abdominal surface laplacian potential contains averaged SW, information unless any bipolar surface channel do not record properly this signal. Consequently EEnG surface recordings can become a low cost technique to study bowel motility non -invasively.**

I. Introduction

The study of the intestinal motility is a outstanding field in gastroenterology due to the fact that it is related with several intestinal diseases. The difficult anatomic access is a technical problem for monitoring intestinal activity [1]. Most methods to study bowel motility are invasive. Only manometric techniques are used in diagnosis. However, this method arises several technical and physiological drawbacks. Nowadays non-invasive techniques based on ultrasounds, intestinal sounds, bioelectromagnetism and myoelectric records, are being developed. Myoelectrical techniques analyze the bioelectrical signal required for smooth muscle contractions, which in the case of small bowel is known as electroenterogram (EEnG). The relationship between the EEnG and the small intestine mechanical activity is widely accepted [2].

Electroenterogram is made up of two waves: slow frequency waves (SW) and spike burst (SB). The first one is a periodical, omnipresent electrical potential and it regulates the maximum rhythm of the intestinal muscle layer contraction. The latter are fast action potential that are only present when contractions appear.

Since the very first experiences of Alvarez and Mahoney in 1922, few authors have recorded myoelectrical abdominal signals applied to the study of the SW component of the electroenterogram in humans [3]. The greatest difficulty in the identification of the SW from abdominal surface recordings is the presence of physiologic interferences, such as the respiration and the ECG. Fig. 1 shows 60 s of a bipolar abdominal surface signal recorded in humans and the simultaneous respiration record. We can appreciate that it is difficult to identify SW in the abdominal surface signals.

In order to reduce these physiological interferences, in this study we have resorted to the use of laplacian potential estimation techniques. As it is known, the laplacian of the surface potential is negatively proportional to two-dimensional divergence of the tangential components of the current density at the body surface and it is proportional to the normal derivative of the normal component of the current density at the body surface [4]. Therefore, theoretically, the laplacian of the potential rejects physiological interferences of electrical origin, improving the resolution given by the potential. In 1975 Hjorth [5] introduced a technique to obtain an estimation of the laplacian potential using five unipolar electrodes arranged in cross (see Fig. 2).

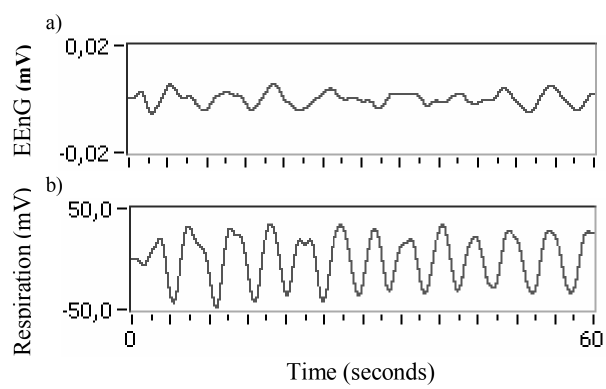

Fig. 1. Human bipolar abdominal surface recording corresponding to channel 1 (a). Respiration recording acquired simultaneously (b).

Currently body surface laplacian mapping is widely used in electrocardiography and electroencephalography to

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G. Prats-Boluda (e-mail: geprabo@eln.upv.es), J. L Martínez-de-Juan (e-mail: jlmartinez@eln.upv.es), F. J. García-Casado (e-mail: jgarciac@eln.upv.es) and J. L Guardiola (e-mail: jguagar@eln.upv.es) are members of the Grupo de Bioelectrónica. Departamento de Ingeniería Electrónica. Universidad Politénica de Valencia. SPAIN.

J. L. Ponce. Servicio de Cirugía General y Digestiva. Hospital Universitario "La Fe" de Valencia. SPAIN

identify bioelectrical sources [6, 7], improving the resolution reached with potential maps.

Therefore, the aim of this study was to get an approximation of the laplacian potential from abdominal body surface recordings using Hjorth estimation method, to identify the SW component of the EEnG in this signal, and compare it to abdominal surface bipolar recordings.

II. MATERIALS AND METHODS

It was carried out 8 recording sessions in 6 healthy subjects, 4 women and 2 men, with ages between 22 and 45 years. During the recording sessions, the patients lie down in supine position. It was used five Ag-AgCl monopolar electrodes with 8 mm in recording diameter. They were listed from one to five. The electrodes were arranged in cross on the abdominal body surface. Electrodes 4, 5 and 2 were lined up with the umbilicus, being electrode 4 2 cm below it and 1.5 cm to the left side. These five electrodes allowed us to get four bipolar recordings using four instrumentation amplifiers. The entries of each amplifier were the potential of the central electrode and the potential of one peripheral electrode. The gain of these amplifiers was set to 2000.The low cut-off frequency chosen was 0.05 Hz, and the high cut-off frequency was set to 35 Hz. Breath and ECG were recorded. All signals were acquired, with a sampling frequency of 1000 Hz. Laplacian potential estimation was software calculated adding the four bipolar surface signals.

$$V_{0i} = (V_i - V_5) \cdot G \quad (1)$$

$$L_s = V_{01} + V_{02} + V_{03} + V_{04} = (V_1 + V_2 + V_3 + V_4) \quad (2)$$

where, i =1..4, Voi is the output of the amplifier i; Vi is the potential recorded by the surface electrode i; G is the instrumentation amplifier gain and Ls is the surface laplacian potential estimation.

First of all, in order to remove the breath interference from abdominal recordings, these signals were adaptively filtered.

Based on the studies of Lin and Chen [8], and Mejía [9] we designed an LMS adaptive filter with a number of weights equal to 32, and a step size, μ=0.05.

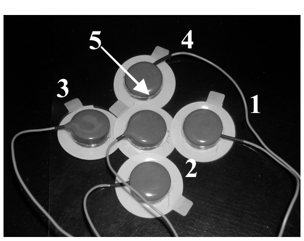

Fig. 2. Configuration of five electrodes arranged in cross developed by Hjorth to estimate laplacian potential.

The block diagram of the adaptive filter is shown in Fig. 3. We have introduced a delay (Tp) of 10 s to compensate the delay caused by the band-pass filter. After being adaptive filtered, the signals were filtered, between 0.1-0.5 Hz. The low cut-off frequency was set to 0.1 Hz to remove slow frequency interferences like the skin potential or motion artefacts [10]. The high cut-off frequency was set to 0.5 Hz to identify the SW component of the EEnG and the breathing interference. EEnG SW spectral frequency ranges from 0.12 Hz (7.2 cpm) at ileum to 0.2 Hz (12 cpm) at duodenum. The frequency associated to breath is about 0.2-0.4 Hz (12-24 cpm) in humans.

Power Spectral Density (PSD) was estimated by unmodified periodograms with 120 s window length. Therefore, the spectral resolution was:

$$\Delta f = 1/T = 1/120s = 0.083 \text{ Hz} \quad (3)$$

To identify the EEnG slow wave component, it was obtained the frequency associated to the maximun energy peak of the PSD (Fmax). It was calculated for every analysis window of each surface recording channel, for the estimated laplacian potential and for the breath. To compare the results given from different recording sessions, the periodograms were normalized.

Finally, the dominant frequencies obtained were statistically studied by means of the Kruskal-Wallis test .

III. RESULTS AND DISCUSSION

First of all, it is difficult to identify the SW of the EEnG by visual inspection of the surface recordings (see Fig. 1). To the authors' knowledge, this has been the fist time than an estimation of the body surface laplacian potential of the EEnG has been obtained.

Fig. 4 (traces a - e) depicts bipolar surface records and the estimated laplacian, band-pass filtered between 0.1-0.5 Hz. Trace f corresponds to the breathing interference. In Fig. 5, periodograms that correspond to the surface signals shown in Fig. 4 are represented. In this case, in all surface recording channels and in the estimated laplacian the frequency associated to the maximum energy peak is 0.14 Hz (8.5 cpm) what is inside the SW frequency range. On the other hand, respiration frequency is 0.37 Hz (22 cpm). However, as it is shown in Fig. 6, commonly it is necessary to remove breath interference from bipolar abdominal body surface recordings to identify the SW of the EEnG.

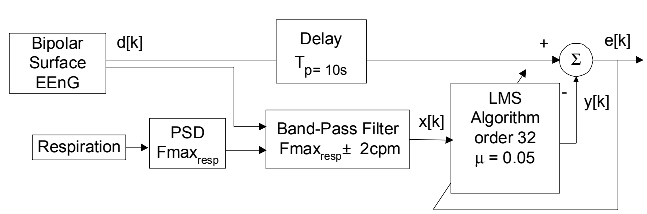

Fig. 3. Block diagram of the adaptive filter to remove breath interference.

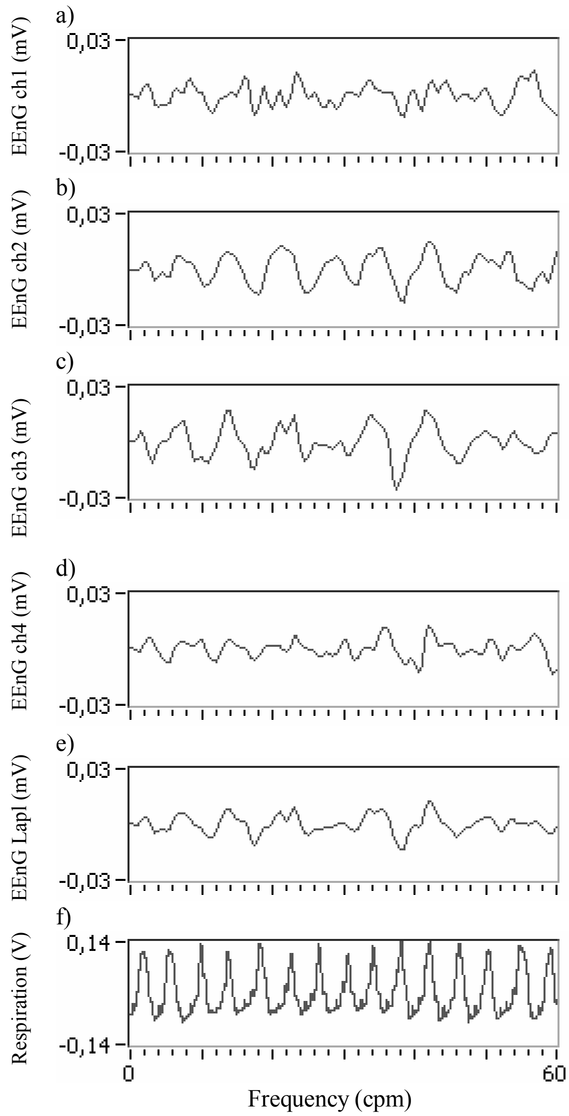

Fig. 4. 60 seconds corresponding to: bipolar surface recordings in abdominal body surface (EEnG) a) ch1, b) ch2, c)ch3, d) ch4, e) their laplacian, f) respiration recording. Recording session III.1.

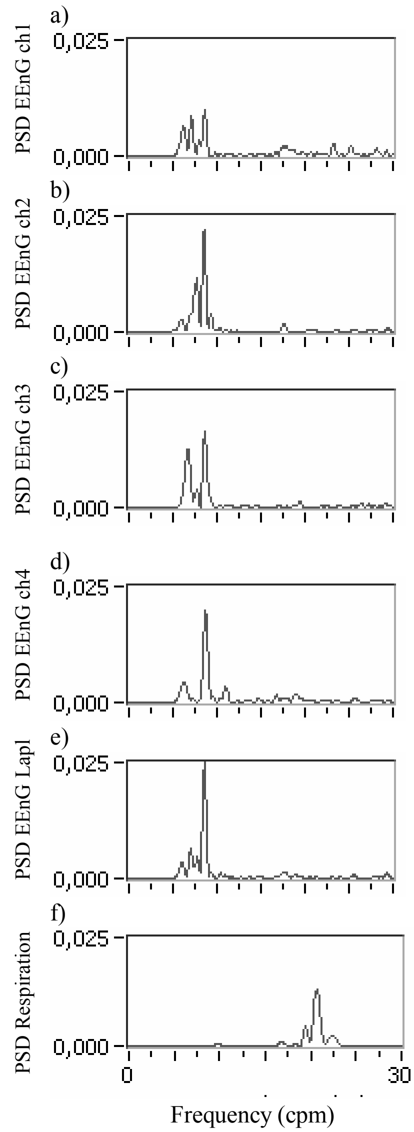

Fig. 5. Normalized periodograms (PSD) corresponding to the signals shown in Fig. 4 .Bipolar surface recordings (EEnG) a) ch1, b) ch2, c) ch3, d) ch4. e) laplacian. f) respiration.

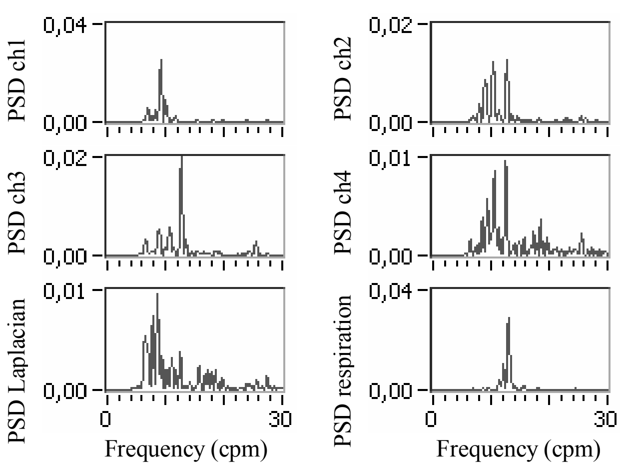

Fig. 6. Peridograms before adaptive breathing filter. Window length 120 s. Session III.1.

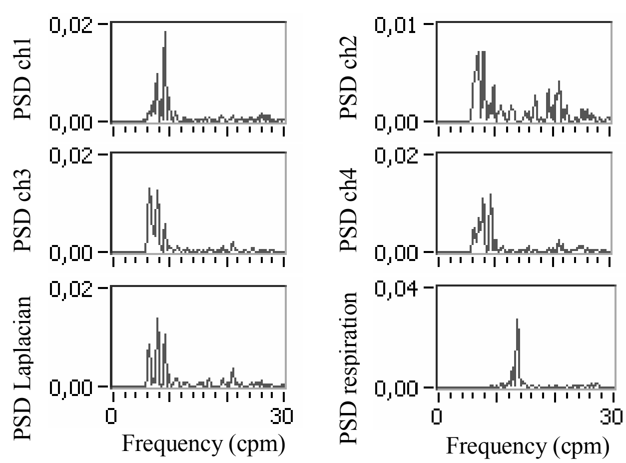

Fig. 7. Peridograms after adaptive breathing filter. Window length 120 s. Recording session VI.1

TABLE I. MEAN FREQUENCY, AND STANDARD DEVIATION OF THE FREQUENCY, ASSOCIATED TO THE PSD MAXIMUM ENERGY PEAK. 8 RECORDING SESSIONS.

Channel \ Session		I.1 N=44	II.1 N=38	II.2 N=18	III.1 N=33	IV.1 N=68	V.1 N=41	V.2 N=47	VI.1 N=53
Ch1	$\overline{F}max \pm \sigma$ (cpm)	8.9 ± 1.4	8.0 ± 1.9	8.9 ± 1.4	8.9 ± 1.4	8.8 ± 1.1	7.9 ± 2.1	7.9 ± 1.2	7.9 ± 1.2
Ch2	$\overline{F}max \pm \sigma$ (cpm)	9.1 ± 2.8	8.1 ± 1.6	9.1 ± 2.8	9.1 ± 2.8	9.8 ± 2.0	7.6 ± 1.0	7.5 ± 1.1	7.5 ± 1.1
Ch3	$\overline{F}max \pm \sigma$ (cpm)	8.7 ± 1.2	8.4 ± 1.5	8.7 ± 1.2	8.7 ± 1.2	9.5 ± 1.8	8.4 ± 2.6	8.0 ± 1.1	8.0 ± 1.1
Ch4	$\overline{F}max \pm \sigma$ (cpm)	9.1 ± 1.6	8.0 ± 1.6	9.1 ± 1.6	9.1 ± 1.6	8.9 ± 1.5	8.2 ± 1.6	7.8 ± 1.1	7.8 ± 1.1
Laplacian	$\overline{F}max \pm \sigma$ (cpm)	8.8 ± 1.5	7.7 ± 1.2	8.8 ± 1.5	8.8 ± 1.5	7.7 ± 1.3	7.6 ± 0.9	7.9 ± 1.0	7.9 ± 1.0
Respiration	$\overline{F}max \pm \sigma$ (cpm)	18.8 ± 1.5	16.5 ± 1.6	18.8 ± 1.5	18.8 ± 1.5	14.4 ± 2.6	13.3 ± 2.4	14.4 ± 0.8	14.4 ± 0.8

In this figure it can be noticed that the discrete laplacian attenuates breathing interference. In general laplacian estimation averages the breathing interference present in the bipolar surface channels.

On the other hand, in some recording sessions, there are channels in which the dominant frequency of the PSD (F_{max}) are below 0.12 Hz (7.2 cpm), see Fig. 7. In spite of this, the dominant frequency (DF) associated to the laplacian PSD, is corresponds to the intestinal SW signal, giving information about the averaged activity of the SW on the abdominal body surface (Fig. 7).

Table I briefs the information about the mean frequency, and the standard deviation associated to the PSD maximum energy peaks for the 8 recording sessions. It is shown that the frequency, in all surface recording channels and in their laplacian, ranges from 0.12 to 0.16 Hz (7.5 to 9.8 cycles per minute), whereas the frequencies of the respiration ranges from 0.21 to 0.31 Hz (12.9 to 18.4 cpm). It is noteworthy that the standard deviation of the laplacian estimate is slightly fewer than deviation of the bipolar surface channels. For instance, Ch2 session I.1, present a high standard deviation. In this case, the SW is poorly identified, because a bad electrode location or due to a great amount of breathing interference picked up in this channel. However its laplacian contains the information of the SW component of the surface EEnG in this region.

As it is shown in table I, the averaged dominant frequencies are set to 8 - 9 cpm. These frequencies are a bit smaller than the frequencies obtained by other authors [3]. It is due to the electrodes location. Chen used two unipolar electrodes set at each side of the umbilicus, where duodenum is supposed to be located. In the present study electrodes were arranged 2 cm below it, where jejunum and ileum are supposed to be placed. In duodenum SW frequency is about 12-11 cpm, decreasing this frequency until 7.2-9 cpm in jejunum and ileum. The peaks below 7.2 cpm are generated by low frequency interferences [10].

The statistical analysis carried out reveals that there are not significant differences ($p<0.05$) between the DF of the laplacian and the surface channels, but there are differences between the surface DF and the breathing DF. Therefore, we can deduce that the abdominal signals recorded do not correspond to breath but with the SW.

IV CONCLUSIONS

It has been demonstrated that the estimated human abdominal surface laplacian potential obtained using Hjorth's method contains the information of the surface EEnG SW component. Besides laplacian potential estimation averages the breathing interference, which is present in bipolar surface recordings.

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