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Characterization of EHG Contractions at Term Labor by Nonlinear Analysis

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Abstract— **Uterine electromyogram on the abdomen of pregnant women (electrohysterogram, EHG) plays an interesting role to evaluate possible risks to the binomial mother-fetus. In this sense, the present study explored the characterization of contractions by EHG during active phase of labor at term in a population at low risk. The goal was to investigate the differences in the contractions generated by women that evolve labor to a vaginal delivery (group 1) to those associated with caesarean section (group 2). Abdominal signals were acquired using Ag-AgCl electrodes in a bipolar configuration and the EHG was obtained by band-pass filtering in the range of 0.3 to 4 Hz. Sample entropy (SampEn) was used to calculate the irregularity of manually selected contractions of the EHG time series. The results showed that it is plausible to discriminate contractions from both groups as the average SampEn was 2.1359 with a standard deviation of 0.0583 for group 1 (N=8), while for group 2 (N=8) was 2.0352 with standard deviation of 0.0946; it was found significant statistical difference between groups as *p* was 0.046. Consequently, the nonlinear analysis via SampEn of EHG could provide an index to evaluate the quality of the active phase labor at term.**

I. Introduction

Pregnancy is a physiological process that involves anatomic-functional, emotional and psychological changes as result of an increment of hormone that enables compliance with the metabolic demands of the fetus and the mother [1]. Despite being a natural process in women, pregnancy could generate some health complications, constituting a significant proportion of the global burden of maternal mortality and morbidity. That is why to monitor both an adequate adaptation of the women to all the physiological changes as well as the correct development of the fetus are important. According to the World Health Organization (WHO) complications during pregnancy are a leading cause of death among women of reproductive age. In 2010, 287,000 women died during pregnancy and childbirth, or after them. Virtually all of these deaths occurred in low-income countries but most of them could have been avoided [2]. One of the major complications during pregnancy is preterm labor (less than 37 weeks of gestation). Preterm labor and subsequent preterm birth is the primary cause of neonatal mortality and neurological morbidity in the short and long term. Its frequency varies between 5% and 12% in developed regions of the world, but can be up to 40% in the poorest regions [3]. Numerous researches have evaluated the possibility of estimating the onset of labor and the early detection of preterm deliveries by means of the characterization of contractions that are obtained by uterine abdominal electromyogram of the pregnant woman (electrohysterogram, EHG) [3-8]. Many studies have shown that different linear parameters in the time, frequency and time-frequency domains may distinguish myometrical properties in uterine EHG contractions between the true term and preterm labor, which is something that other traditional contraction-monitoring devices cannot perform [9-12].

Although the number of maternal deaths in Mexico has decreased from 1,477 to 992 deaths during the period 1990-2010, the maternal mortality ratio (the number of maternal deaths per 100,000 live births) has remained fairly constant, with a slight downward trend in recent years. Thus, the maternal mortality ratio (MMR) declined from 61 deaths per hundred thousand births in 1990 to 51.5 in 2010 [3]. Additionally, since the eighties the WHO proposed that births by caesarean section should be between 10% and 15% [13]. According to the National Survey on Health and Nutrition in 2012 (ENSANUT 2012) the resolution of labor in women with ages between 20 to 49 years old, with a live birth in the five years preceding the survey, shows that the total percentage of births by caesarean section was 46.2% (20.5% planned and 25.7% emergency) which exceeds the maximum limit recommended by the Standard Mexican Official 007, which is 20% [14].

Consequently, it is relevant to add knowledge in a quantitative way and by a noninvasive technique as EHG, of the physiological phenomenon of active phase of labor at term when it is finished by caesarean section. Taking into account that the uterus is composed of billions of intricately

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interconnected cells whose responses may be assumed as nonlinear process, their dynamic could be analyzed by techniques as the sample entropy, among others. Nonlinear techniques have been applied to analyze bursts of uterine electrical activity with promising results as the fractal dimension [8]. This study analyzes the uterine information during the active phase of labor at term [7, 15, 16] and specifically, the characterization of uterine contractions by EHG to discriminate between evolving labor to a vaginal delivery or to a caesarean section in a low risk population. The hypothesis of the study is that uterine contractions associated to vaginal delivery and to caesarean section possess different underlying physiological processes that can be characterized by measuring the irregularity properties of the EHG signal.

II. Materials

A. Subjects

Sixteen singleton pregnancies without complications according to their clinical history, physiological assessment, and blood sample test were studied at CIMIGen (Maternal and Child Research Center, Study Group at Birth). Women from 18 to 37 years old, with gestational age ranging from 37 to 41.4 weeks and in active phase labor at term, were included in this study, see Table I. All of them signed an informed consent according to Helsinki guidelines to collect the uterine signal during their labor. Signals from supine or side-lying patients were recorded during morning hours (9–12 h) in a clinical environment. There were two groups of patients: group 1 (G1) includes patients whose labor resulting in a vaginal delivery, and group 2 (G2) involves patients whose labor leads to cesarean section. G1 and G2 included eight subjects each (N=8).

B. Experimental setup

The uterine signals included in the study were collected at CIMIGen from 2010 to 2012. The recordings last from several minutes to hours according to the duration of the labor. The fetal ECG and Uterine Contractions Monitor Monica AN24™, (Monica Healthcare Ltd, Nottingham, UK) was used to acquired the abdominal signal whose typical Ag-AgCl electrode setting is shown in Fig. 1. One electrode was located on the mid-line as close as 6 cm above the symphysis pubis and the other on the mid-line so that the bottom edge of the electrode was just below the top edge of the umbilicus. The electrodes were positioned in a bipolar configuration after cleaning the abdominal area with alcohol swab and abrade the skin with fine sandpaper to reduce skin impedance. Particularly, electrode 5 against 2 provided the raw signal to be processed in this study.

III. Methodology

A. Acquisition and Preprocessing

The abdominal signals were acquired with a sampling frequency of 900 Hz and the lower and upper cut-off frequencies of the Monitor Monica AN24 were 0.2 and 180 Hz, respectively. To extract the EHG signal from the acquired abdominal signal (electrode 5), it was digitally low-pass filtered using a cutoff frequency of 4 Hz. Afterward, the filtered signal was downsampled to 10 Hz and high-pass filtered with cutoff frequency of 0.3 Hz. The EHG frequency band of this study is in agreement with the frequency band in other studies [7, 17]. In order to manually select whole contractions, an envelope signal was obtained by the absolute value of the Hilbert transform of the EHG. Bursts of uterine electrical activity of both groups in conjunction with the envelope signal can be seen in the representative examples of Fig. 2. Also, to corroborate that the selected EHG section corresponded to a whole contraction the Hilbert-Huang time-frequency representation (HH-TFR) using the empirical mode decomposition (EMD) was obtained; Fig. 3 shows the HH-TFR for the signals in Fig.2.

B. Sample Entropy

To obtain the average sample entropy, in this study five whole contractions were selected from the EHG time series. Sample entropy (SampEn) is a measure of the irregularity of a time series which is calculated as:

$$SampEn(m,r,N) = -\ln \frac{U^{m+1}(r)}{U^{m}(r)} \quad (1)$$

where m corresponds to the size of pattern vectors in the time series, r indicates a tolerance when one is looking for pattern vectors, N is the length of the original time series and $U^{m}(r)$ provides the probability of occurrence of pattern vectors [18]; less predictable or more irregular time series as white noise exhibit higher sample entropy. In this study m was fixed to 2 and r was equal to 0.15; however, in a future

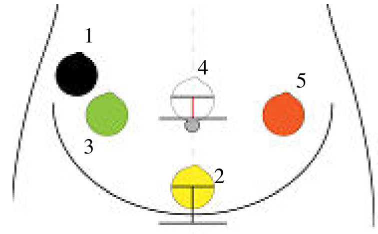

Fig. 1. Abdominal electrodes configuration. The black electrode (1) was positioned towards the back being the ground reference while the yellow electrode (2) was the negative reference for bipolar recordings. The green (3), white (4) and orange (5) were the positive or active ones.

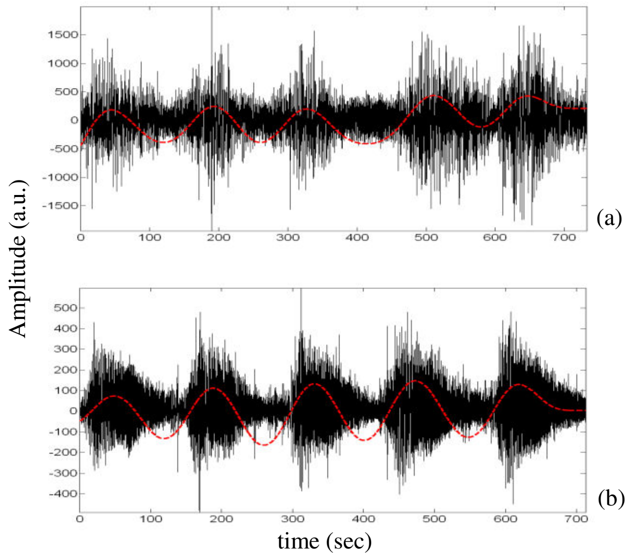

Fig 2. Examples of acquired EHGs in black color and their envelope signals in red from (a) vaginal delivery (G1) and (b) caesarean section (G2).

work it is necessary to explore different values of m and r to review the effect of both parameters when SampEn is applied to EHG.

TABLE I. CLINICAL CHARACTERISTICS OF THE WOMEN AT ACTIVE PHASE OF LABOR AT TERM (N=16)

Group	**Age (years)**	**Cervical dilatation (cm)**	**Gestational age (weeks)**
Delivery (G1)			
1	23	6	40.2
2	28	3	39
3	27	4.5	41.4
4	37	9	38
5	22	4	38.4
6	24	8	38
7	26	5	40.3
8	32	9	40
Mean±std	27.37±5.01	6.06± 2.33	39.41±1.24
Caesarean (G2)			
1	31	0	37.3
2	37	0	37
3	24	3	40
4	18	1.5	40
5	31	0	40.6
6	32	2	40.5
7	20	6	39.3
8	23	3	40.1
Mean±std	27±6.67	1.93±2.07	39.35±1.41

C. Statistical analysis

The statistical analysis was performed on the average values of SampEn of both groups. To test for statistical differences (p value $\leq$ 0.05) a non-parametric Kruskal-Wallis ANOVA test was applied.

IV. RESULTS AND DISCUSSION

Table I lists the characteristics of the women included in this study. The statistical test did not reveal differences concerning ages and weeks of gestational age. However, statistical difference was found for cervical dilatation; mean value for G2 is 1.93 cm and standard deviation of 2.07 cm while for G1 the mean value is 6.06 cm with a standard deviation of 2.33 cm. In this work changes were expected in the irregularity of the time series between groups, Fig.2 shows examples of EHG contractions of G1and G2 groups supporting this assumption; the contractions of G1 patient look more irregular when is contrasted with the contractions of the G2 patient. Furthermore, time-frequency (TF) domain analysis by HH-TFR was performed on the contractions. The HH-TFR was selected since the EMD does not require the selection of a kernel for the analysis and is exclusively data dependent (adaptive), also it has very good TF resolution. Fig. 3 shows the HH-TFR of the contractions of Fig. 2. It is plausible to observe that the magnitude of the TF information of each contraction belonging to G1 goes from 0.3 up to 3.5 Hz. In contrast, the TF information of the contractions of G2 is split in frequency bands ranging from 0.3 to 1 Hz, 1.5 to 2 Hz and 3 to 4 Hz. The former findings need to be deeply investigated and contrasted to the low frequency band between 0.1 and 1.2 Hz named FWL, that is presumed to be related to the propagation of the electrical activity along the uterus and the high frequency band, between 1.2 and 4.7 Hz named FWH, assumed to be related to the excitability of the uterus [9, 19] reported in the literature [20]. Also, it is noticeable the periodicity (regularity) of the TF information for the G2 subject in comparison with the G1 subject, which is in agreement with the observation that weak labor contractions typical for failure in progress in the first stage of labor showed predominantly periodic structures [21].

The statistical Kruskal-Wallis ANOVA test applied to the average SampEn values summarized in Fig. 4 by the box-plots reveals that contractions of both groups are different with lower values for G2, indicating more regular EHG signals, than for G1. Statistically significant difference was found between groups since p= 0.046. Furthermore, higher dispersion of the SampEn values is evident for G2 than for G1.

V. CONCLUSION

Many biological electrical processes are thought to be nonlinear in origin. In recent studies nonlinear signal processing was successfully applied on EHG signals for classification of preterm and term labor delivery groups. Consequently, considering that EHG could be regarded as a

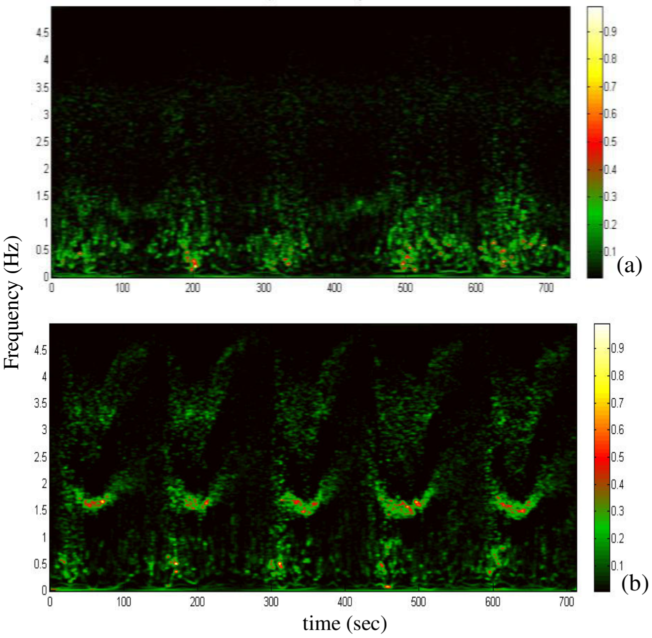

Fig. 3. Time-frequency representation by HH of examples of contraction signals, (a) vaginal delivery and (b) caesarean section.

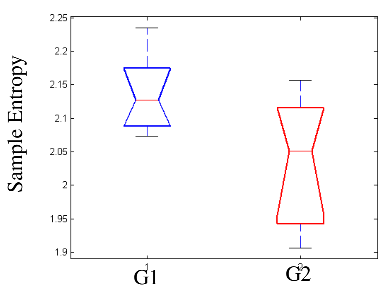

Fig. 4. Average sample entropy Kruskall-Wallis statistical test. In blue vaginal delivery group and in red, the caesarean section group.

complex signal and knowing that SampEn is a measure of the irregularity of finite length time series, in this work it was demonstrated that contractions evolving active phase labor at term to a vaginal delivery or to a caesarean section possess different nonlinear characteristics, in a low risk population. Future work needs to increase the number of patients to validate a quantitative clinical index based on SampEn, possibly combined with others features as cervical dilatation, to distinguish women that are going to need a caesarean section. Also, the procedure to select whole contractions needs to be improved.

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