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Prediction of labor using non-invasive Laplacian EHG recordings

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Abstract— **Non-invasive electrohysterogram (EHG) recordings could be used as an alternative technique for monitoring uterine dynamics. Bipolar recordings of EHG have proven to provide valuable information to predict labor. Recently it has been stated that uterine EHG bursts could also be identified in Laplacian recordings on abdominal surface. Taking into account that Laplacian potential technique permits to acquire more localized electrical activity than conventional recordings; these recordings could also be helpful for deducing uterine contraction efficiency. The aim of this paper is to examine the feasibility of Laplacian potential EHG recording for labor prediction and to compare it with monopolar recordings. To this purpose, a total of 42 EHG recordings were acquired from women of similar gestational age: 29 antepartum patients, and 13 patients in labor. Then linear and non-linear classifiers have been implemented using EHG burst parameters as input features. Experimental results show significant differences in temporal and spectral parameters in both monopolar and Laplacian potential recordings between the two groups. In addition, support vector machine based classifier achieved an accuracy of 93% for labor prediction for monopolar recordings, 92% for bipolar recordings and 91% for Laplacian potential.**

I. INTRODUCTION

Preterm birth and its associated complications are one of the most important problems in perinatology, since they represents about 7% of the total number of babies born each year and contribute to about 85% of all perinatal deaths [1]. The complications of preterm birth include significant neurological, mental, behavioral and pulmonary problems in later life. One of the determining factors of tocolytic treatments effectiveness and therefore of the prolongation of fetal development in uterus is the early detection of preterm birth, which depends upon the understanding of the mechanisms that initiate labor [2].

The most common and at the same time most difficult and important task that obstetricians have to face may be the diagnosis of labor. Accurate prediction of labor in normal pregnancies may contribute to minimize unnecessary hospitalizations, interventions and expenses. On the other hand, diagnosis of preterm labor will also allow clinicians to start earlier any necessary treatment in women with true labor; and avert unnecessary treatment in those who are simply having preterm contractions but not leading to labor. Unfortunately, to date there is no effective technique for predicting labor [2].

Electrohysterogram (EHG) is the recording of uterine electrical activity on abdomen surface. It has emerged as an alternative technique for characterizing the human parturition state since changes in uterine electrical activity have been associated with the progression of pregnancy and the onset of labor. Thus EHG can provide useful information for deducing contraction efficiency [2, 3]. To date, many efforts have been devoted to the analysis of contraction strength which seems to be related to the frequency and intensity of action potentials in bipolar EHG recording [3;4]. Latest studies have focused on the analysis of EHG signal propagation since the spreading of electrical activity in the myometrium is the first trigger of a coordinated and effective contraction [5-7]. For this purpose, a multi-lead EHG recording is usually performed by placing monopolar cutaneous electrodes at abdominal surface. Nevertheless, monopolar and even bipolar recordings have been shown to have low spatial selectivity of the charge dipoles covering a large recording area in the surroundings of the electrode due to the volume conduction effect [8]. In this sense, Laplacian potential recording has been shown to acquire more localized information which may provide additional information for labor prediction. In a previous work it has been proven that Laplacian potential of EHG signal can be detected on abdomen surface of pregnant woman during labor [9]. Therefore, the aim of this paper is to examine the feasibility of this non-invasive Laplacian potential EHG recording for labor prediction and to compare it with simultaneously recorded monopolar EHG.

II. MATERIAL AND METHODS

A. *Signal acquisition*

In this study, 42 pregnant women underwent recording sessions at Hospital Universitario y Politécnico La Fe de Valencia. All subjects provided written, informed consent. Hospital ethics committee approved the study protocol. The subjects were healthy women having uneventful singleton pregnancies. The recordings were grouped into two set: G1: labor, with N=13; G2: antepartum (i.e, non-labor), with N=29. Their gestational age was 39.8±1.4 weeks and 39.7±1.1 weeks for G1 and G2 group respectively. All G1 patients ultimately delivered spontaneously at term within 24 h of EHG recording, while G2 patients delivered spontaneously at term more than 24 h from EHG measurement.

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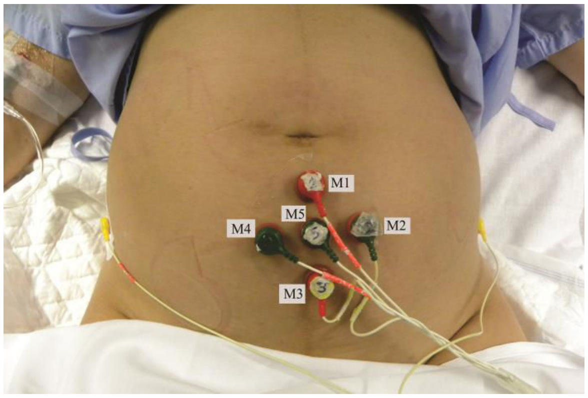

Fig 1. Configuration of surface electrodes for obtaining five monopolar EHG recordings (M1-M5).

For each recording session, the skin was carefully prepared using an abrasive paste in order to reduce the contact impedance. Five monopolar Ag/AgCl reusable wet electrodes arranged in the form of a cross as shown in fig. 1 were used for obtaining monopolar EHG signals, being 25 mm the inter-electrode distance. The electrodes 1, 3 and 5 were placed on the uterine median axis and the 1-5 electrode pair on the middle of the uterus (fundus to symphysis). Reference electrodes were placed on each hip of the woman. All recorded EHG signals were band-pass filtered at [0.05, 35] Hz and sampled at 500 Hz.

Simultaneous non-invasive pressure recordings (TOCO) for both G1 and G2 patients were obtained by means of a tocodynamometer placed on abdominal. Intrauterine pressure (IUP) recording was also performed using the ACCU-Trace intrauterine pressure catheter during parturition for G1 group patients. These pressure signals, which are traditionally used to monitor uterine dynamics, were conditioned using the maternal –fetal monitor (Corometrics 170 series, GE Medical systems) and acquired at 4 Hz sampling frequency. All the collected data were displayed in real time and stored digitally for subsequent analysis.

B. *Data analysis*

In order to remove undesired components and to reduce the amount of data, signals were digitally bandpass filtered between 0.1 and 4 Hz and resampled at 20 Hz. Discrete Laplacian signal was computed from the five monopolar EHG recording according to equation 1), Hjorths' method [10].

$$L_D = \frac{4}{b^2}\left\{V_5 - \frac{1}{4}\left(V_1 + V_2 + V_3 + V_4\right)\right\} \qquad (1)$$

where V_i are the surface potentials at electrode 'i' (i=1,…,5), L_D is the discrete Laplacian estimation at electrode 5 (central electrode) and b is the interelectrode distance (2.5 cm).

All the EHG bursts were then manually segmented by experts. The EHG bursts had to correspond in time to increases in uterine pressure recordings, and no artifact evidence must have been observed during the contraction. A total of 108 EHG bursts of G1 and 58 EHG bursts of G2 were involved in the study.

Subsequently, in order to characterize the EHG bursts from each monopolar and discrete Laplacian signal, the following parameters were obtained:

- Duration
- Mean frequency
- Median frequency
- Frequency standard deviation (FSD)
- Dominant frequency calculated in frequency range (DF_1: 0.1-3 Hz) and (DF_2: 0.34-3 Hz)
- Subband energy (NE_1: 0.1-0.34 Hz, NE_2: 0.34-0.6 Hz, NE_3: 0.6-1 Hz) normalized respect to total energy
- Sample entropy (signal pattern length m=5 samples, pattern matches margin r=0.2).

These parameters have been used in different previous works to characterize bipolar EHG bursts [11-14]. Spectral parameters were obtained from unmodified periodogram of signal bursts.

Linear and quadratic discriminant analyses (QDA) were then performed and a support vector machine (SVM) classifier using a radial basis function kernel was implemented. In order to determine the classifiers generalization capacity of the new data, two-fold cross-validation was used. 50% of the data was used for training and the remaining 50% was used for testing the classifiers. Due to the random nature of the set of data used for training and testing, the cross-validation process was carried out 50 times to minimize bias. The combination of features that gave maximum classifier accuracy for labor prediction was determined by means of a sequential forward feature selection algorithm. Then, such combination was used for the three classifiers in order to compare their performance for the total of data (training set and test set).

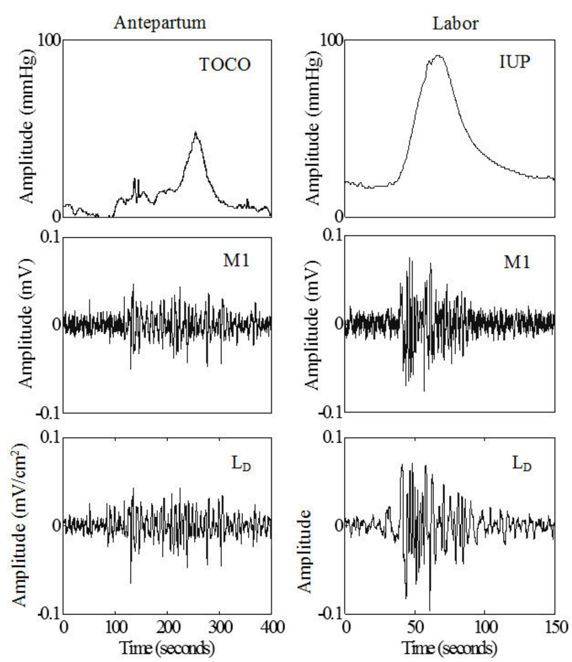

Fig 2. EHG recordings (Monopolar M1 and discrete Laplacian L_D) acquired simultaneously with TOCO in antepartum and IUP in labor.

TABLE I: MEAN AND STANDARD DEVIATION OF EHG BURSTS PARAMETERS FOR ANTEPARTUM PATIENTS AND IN LABOR PATIENTS.

Parameter	Group	M1	M2	M3	M4	M5	L_D
Duration (seconds)	G2	97.5±39.7	98.6±39.9	103.2±37.4	101.9±39.8	101.4±39.2	103.84±34.5
	G1	55.8±8.8	53.9±8.7	60.9±8.3	61.0±8.7	54.8±9.6	63.2±8.8
Mean frequency (Hz)	G2	0.38±0.06	0.37±0.06	0.24±0.05	0.24±0.04	0.24±0.05	0.23±0.04
	G1	0.41±0.09	0.39±0.09	0.33±0.06	0.33±0.06	0.31±0.07	0.33±0.06
Median frequency (Hz)	G2	0.33±0.07	0.32±0.07	0.20±0.05	0.20±0.05	0.21±0.06	0.20±0.05
	G1	0.38±0.11	0.37±0.11	0.28±0.08	0.29±0.09	0.28±0.09	0.30±0.09
FSD (Hz)	G2	0.20±0.02	0.20±0.03	0.14±0.03	0.13±0.03	0.13±0.03	0.13±0.02
	G1	0.17±0.04	0.17±0.03	0.17±0.03	0.17±0.03	0.15±0.03	0.17±0.03
DF_1 (Hz)	G2	0.25±0.11	0.27±0.11	0.16±0.07	0.16±0.05	0.16±0.07	0.16±0.06
	G1	0.36±0.14	0.35±0.15	0.24±0.11	0.26±0.11	0.24±0.13	0.24±0.11
DF_2 (Hz)	G2	0.44±0.09	0.44±0.08	0.42±0.06	0.39±0.04	0.41±0.04	0.41±0.04
	G1	0.46±0.08	0.46±0.08	0.50±0.07	0.49±0.06	0.44±0.07	0.48±0.06
NE_1	G2	0.52±0.15	0.54±0.14	0.82±0.11	0.83±0.10	0.82±0.12	0.84±0.11
	G1	0.41±0.25	0.44±0.25	0.74±0.16	0.73±0.19	0.64±0.19	0.72±0.20
NE_2	G2	0.33±0.13	0.31±0.12	0.14±0.10	0.14±0.10	0.15±0.11	0.14±0.10
	G1	0.44±0.21	0.43±0.21	0.31±0.16	0.33±0.17	0.31±0.17	0.33±0.17
NE_3	G2	0.14±0.06	0.14±0.06	0.03±0.02	0.03±0.02	0.03±0.02	0.02±0.02
	G1	0.15±0.10	0.13±0.09	0.05±0.03	0.05±0.03	0.05±0.06	0.06±0.04
Sample entropy	G2	0.250±0.019	0.256±0.020	0.218±0.025	0.209±0.026	0.211±0.022	0.207±0.022
	G1	0.248±0.026	0.244±0.020	0.252±0.020	0.249±0.024	0.223±0.023	0.246±0.029

Group: G1: Labor; G2: Antepartum. Recordings: M1-M5: Monopolar EHG recordings, L_D.discrete Laplacian EHG recording,

III. RESULTS

Fig 2 shows a typical EHG recording acquired simultaneously with TOCO in antepartum (left traces) and with IUP in labor (right traces). Before the contraction occurs, a slightly lower background noise seems to be present in the estimated Laplacian potential of EHG than in monopolar recording. This is probably due to the ability of Laplacian recordings to reduce ECG interference [9]. It can be noticed that monopolar and discrete Laplacian EHG bursts in antepartum present lower amplitude than in labor as previously reported by other authors [11, 15]. Additionally, it can be also observed that EHG bursts duration in labor is lower than in antepartum.

Table 1 summarizes the results of the set of parameters computed to characterize the EHG bursts of monopolar and Laplacian signals in antepartum and labor patients. It is confirmed that for both recording techniques duration of EHG bursts is considerably smaller and less dispersed in labor patients than in antepartum patients (97.49±39.66 s vs. 55.84 ±8.77 s for M1 recording). In addition mean frequency, median frequency, DF_1, DF_2, and NE_2 increase as delivery approaches, whereas NE_1 tends to decrease. Moreover, median frequency and DF_1 (frequency peak calculated in 0.1-3 Hz) seems to provide greater difference between antepartum and labor patients than mean frequency and DF_2 calculated in 0.34-3 Hz. Nevertheless neither FSD, nor NE_3, nor sample entropy showed clear tendencies as delivery approaches. It is also noteworthy that the bursts' median frequency values for monopolar M3, M4, M5 and L_D are noticeably lower in both antepartum and labor patients than that of M1 and M2. This finding may indicate the presence of a larger baseline fluctuation of the recorded signal in M3, M4 and M5 recordings due to possible differences in the recording conditions.

TABLE II: CLASSIFIERS' MEAN ACCURACY FOR THE TEST GROUP USING THE BEST COMBINATION OF FEATURES (DURATION, DF_1 AND NE_1)

Classifier	M1 (%)	M2 (%)	M3 (%)	M4 (%)	M5 (%)	L_D (%)
LDA	89.03	89.79	92.88	89.78	90.87	89.93
QDA	90.90	93.96	92.77	88.71	89.74	89.37
SVM	92.06	94.30	94.58	89.41	92.84	90.80

Table II shows the classifiers' mean accuracy for the test group using the best combination of features provided by the sequential forward feature selection algorithm. They were: burst duration, DF_1 and NE_1. Firstly it can be seen that, as expected, non-linear classifiers (QDA and SVM) provide slightly higher accuracy than the linear one, being the best result obtained using SVM method. The accuracy of both monopolar and L_D recording classifier using SVM is about 93% and 91% respectively. This accuracy is to some extent unbalanced towards sensitivity (sensitivity of around 97% and specificity of around 80%; not shown). The results for bipolar recordings using SVM method (not shown) yield a mean accuracy of 92.4 % with very little differences among bipolar channels.

IV. DISCUSSION

In this paper, it was intended to examine the feasibility of monopolar and Laplacian potential of EHG for predicting labor. To this end, a set of parameters in temporal and spectral domain and also non-linear properties was computed from EHG bursts recorded in anterpartum and labor patients of similar gestational age. This study verifies that the change from antepartum to labor causes significant increases in EHG burst dominant frequency and causes shifts of signal frequency content towards high frequency. This latter was reflected in the increase of mean frequency and median frequency, and the normalized subband energy in 0.34-0.6 Hz; and also in the decrease of the normalized subband energy in 0.1-0.34 Hz. This finding agrees with those reported in the literature for bipolar EHG recordings [12, 13]. By contrast, sample entropy which has been proven to provide information for distinguishing term and preterm delivery groups [13], did not provide the expected results. It has been reported that as the time of gestation progresses, the average sample entropy values for term and pre-term delivery recordings drop indicating higher predictability of the signals as the delivery approaches [13]. These controversial results may be due to the fact that in the present study this parameter was not computed for the whole EHG recordings but rather for the EHG bursts only.

With respect to the features to be used by the classifier, the results showed that the best prediction accuracy was obtained using the burst duration, DF_1 and NE_1, which suggests that most of the computed EHG frequency parameters contain redundant information among them. In addition, the results exhibited the feasibility of both monopolar and Laplacian potential recordings of EHG for labor prediction. The prediction accuracy is slightly higher for monopolar than for bipolar and discrete Laplacian recording; and similar to that reported for bipolar recordings when using the signal frequency peak calculated in 0.34-1 Hz (DF_2) and burst duration [12]. The fact that even far from delivery, still about 10% to 20% of the uterine bursts present higher-frequency activity, and that not all the bursts within 24 hours of delivery but only about 80% to 90% present higher-frequency activity [16], limits the accuracy of these classifiers. The combination of the information from multiple bursts of the same patient, and the inclusion of additional parameters directly related to propagation velocity of EHG bursts [5-7] could help to overcome this limitation.

Finally to remark that the accuracy achieved using Laplacian potential of EHG is slightly higher than the worst monopolar recording but lower than the best monopolar recording. This is probably due to the fact that the Laplacian potential was estimated from the 5 monopolar recordings and covered a large recording area. In this respect, the use of concentric ring electrodes of smaller size to estimate Laplacian potential that have proven to achieve higher spatial resolution, [8, 9] may provide more information for labor prediction. Nevertheless this should be confirmed in future studies.

V. Conclusion

Our results suggest that physiological changes from antepartum to labor causes significant decreases in EHG burst duration, increases dominant frequency and shifts signal frequency content towards high frequency in both of monopolar and discrete Laplacian signals. In addition, it was developed a SVM classifier using only three parameters that permits to achieve an accuracy of above 90%, which suggests the feasibility of these kinds of recordings for predicting labor.

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