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Recording of Electrohysterogram Laplacian Potential

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Abstract—**Preterm birth is the main cause of the neonatal morbidity. Noninvasive recording of uterine myoelectrical activity (electrohysterogram, EHG) could be an alternative to the monitoring of uterine dynamics which are currently based on tocodynamometers (TOCO). The analysis of uterine electromyogram characteristics could help the early diagnosis of preterm birth. Laplacian recordings of other bioelectrical signals have proved to enhance spatial selectivity and to reduce interferences in comparison to monopolar and bipolar surface recordings. The main objective of this paper is to check the feasibility of the noninvasive recording of uterine myoelectrical activity by means of laplacian techniques. Four bipolar EHG signals, discrete laplacian obtained from five monopolar electrodes and the signals picked up by two active concentric-ringed-electrodes were recorded on 5 women with spontaneous or induced labor. Intrauterine pressure (IUP) and TOCO were also simultaneously recorded. To evaluate the uterine contraction detectability of the different noninvasive methods in comparison to IUP the contractions consistency index (CCI) was calculated. Results show that TOCO is less consistent (83%) than most EHG bipolar recording channels (91%, 83%, 87%, and 76%) to detect the uterine contractions identified in IUP. Moreover laplacian EHG signals picked up by ringed-electrodes proved to be as consistent (91%) as the best bipolar recordings in addition to significantly reduce ECG interference.**

I. Introduction

Preterm birth and its associated complications is one of the most important problems in perinatology, since it represents about 7% of the total number of babies born each year and contributes to about 85% of all perinatal deaths [1]. The complications of preterm birth include significant neurological, mental, behavioral and pulmonary problems in later life [1]. One of the determining factors of tocolytic treatments effectiveness and therefore for 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].

While a few of the currently used techniques can identify some of the signs of oncoming labor, none of them offer objective data that accurately predicts labor over a broad range of patients. To date, intrauterine pressure (IUP) is used as the gold standard for monitoring the uterine contractions. It has been shown to provide reliable information of uterine contractions [2]. However, its clinical application for early detection of preterm birth is limited since membrane rupture is required for the placement of the intrauterine pressure catheter, which might increase the incidence of intrapartum infection and has been reported to cause uterine perforation or placental abruption in rare cases [2].

Instead of using intrauterine pressure catheters, uterine activity is typically monitored with a strain-gauge-based sensor on abdominal surface (Tocodynamometer, TOCO). TOCO provides frequency and approximate duration of contractions [2]. However TOCO has been shown to be unreliable as a predictor for preterm or even term labor since the measurements obtained are inaccurate and depend on the subjectivity of the examiner [2]. Moreover, no additional information about contraction efficiency, i.e. whether they lead to true labor or not, can be deduced from this measurement.

The measurement of uterine electromyogram has been proposed as an alternative for monitoring the uterine contractions. Moreover uterine electrical activity can also be detected on abdominal surface (electrohysterogram, EHG), and this latter is temporally correlated with both internal uterine electromyogram and with the contractile activity [3].

To date, many efforts have been attended to the analysis of contraction strength which seems to be related to the action potentials frequency of EHG [2, 3]. Latest studies have focused on the analysis of EHG signal propagation during a contraction to study the synchronization mechanisms which is a crucial factor for deducing contraction efficiency. For this purpose, a multi-lead EHG recording is usually performed by placing an array of monopolar cutaneous electrodes at abdominal surface. Nevertheless, monopolar and even bipolar recording have been shown to have low spatial selectivity of the current dipoles because of the volume conduction effect [4]. In this sense, laplacian potential recording has been proposed in order to increase the spatial resolution of surface recording of other biosignals [4, 5]. Moreover, cardiac interference is also present in EHG recording; and previous studies on external intestinal myoelectrical recordings have shown that laplacian potential recording permits to reduce this interference [6].

The aim of this paper is to examine the feasibility of non-invasive recording of laplacian potential of the EHG signal, and to compare the uterine contraction detectability of TOCO, bipolar and laplacian recordings of EHG.

II. Material and Methods

A. Signal acquisition

Parturition recordings were made on 5 women admitted to the Hospital Universitario y Politécnico La Fe de Valencia for spontaneous or induced labor. All subjects provided

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written, informed consent. The subjects were healthy women in the first stage of labor having uneventful singleton pregnancies, and their estimated gestational age was 37-41 weeks. The duration of each recording session ranged from 30 minutes to 2 hours. A recording system was developed with Labview ® to obtain the simultaneous recording of EHG signals, Tocographic and Intrauterine pressure.

For each recording session, the skin was carefully prepared using an abrasive paste in order to reduce the contact impedance. Five monopolar Ag/AgCl electrodes arranged in the form of a cross were used for obtaining monopolar EHG signals, being 25 mm the inter-electrode distance. Two laplacian potential recordings of EHG were directly obtained using active concentric rings electrodes. The ringed-electrode characteristics can be found in a previous work [6]. All monopolar electrodes and the active concentric ring electrodes were placed on abdominal surface according to Fig. 1. 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. Both monopolar EHG signal and laplacian potential of EHG were band-pass filtered at [0.05, 35] Hz and sampled at 500 Hz.

At the same time, a tocodynamometer placed on abdominal surface and the ACCU-Trace intrauterine pressure catheter were used to obtain Tocographic and IUP signals respectively. These signals were conditioned using the maternal –fetal monitor (Corometrics 170 series, GE Medical systemas) 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*

Firstly four bipolar EHG signals and the discrete laplacian signal were digitally computed from the five monopolar EHG recording and then resampled at 50 Hz. Bipolar and discrete Laplacian EHG signals were obtained as follows:

$$B_1 = V_1 - V_5;\ B_2 = V_5 - V_3;\ B_3 = V_4 - V_5;\ B_4 = V_5 - V_2 \quad (1)$$

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

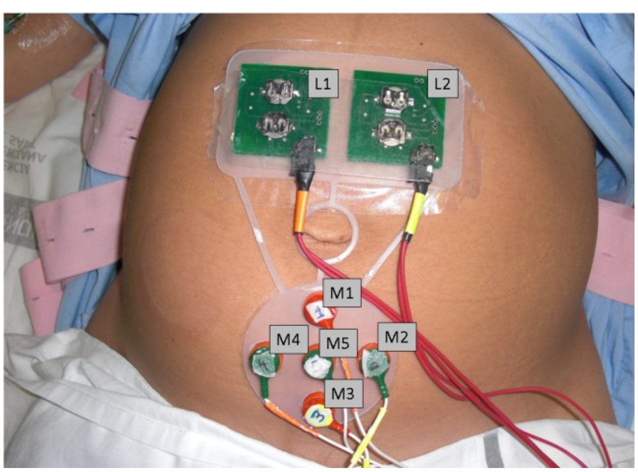

Fig 1. Configuration of surface electrodes for obtaining simultaneously five monopolar EHG recordings (M1-M5) and two laplacian potential recordings using active concentric-ringed-electrodes (L1 and L2).

where V_i are the surface potentials at electrode i (i=1,…,5). B_j is the estimated bipolar EHG signal (j=1,…,4). L_D is the discrete Laplacian estimation at electrode 5 (central electrode) [5].

Uterine contractions were visually identified on the different recordings by experts. To evaluate contraction consistency, it was obtained the contractions consistency index (CCI), also used by [7], for both electrohysterographic and Tocographic signals.

$$CCI = \frac{N_C}{\frac{1}{2}\left(N_T + N_E\right)} \quad (3)$$

where N_T is the number of contractions detected by IUP (considered the Gold standard for monitoring uterine activity), N_E is the number of contractions detected in the bipolar EHG, Laplacian potential of EHG, or Tocographic signals and N_C is the number of consistent contractions. Contractions were considered to be consistent when the peak of a contraction from the EHG or Tocographic signal was found within plus or minus 10 seconds of the peak of a contraction from the IUP recording.

III. Results and Discussion

Figure 2 shows an example of monopolar, bipolar and laplacian recordings of EHG in rest state (without contraction). It can be observed that maternal ECG interference strongly affects monopolar EHG recordings. This interference is weaker in bipolar recording; still it can also be easily identified; whereas it is significantly reduced in the signal acquired by the ringed-electrode. These results are in agreement with previous studies that used active concentrig rings electrodes for the recording of myoelectrical signals of intestinal origin on abdominal surface [6]. In that study, signals from ringed-electrodes presented significantly higher signal-to-ECG interference ratio than simultaneous bipolar recordings.

Figure 3 shows an example of EHG recordings (bipolar, discrete laplacian and active concentric ring laplacian) acquired simultaneously with IUP and TOCO during a contractile activity period.

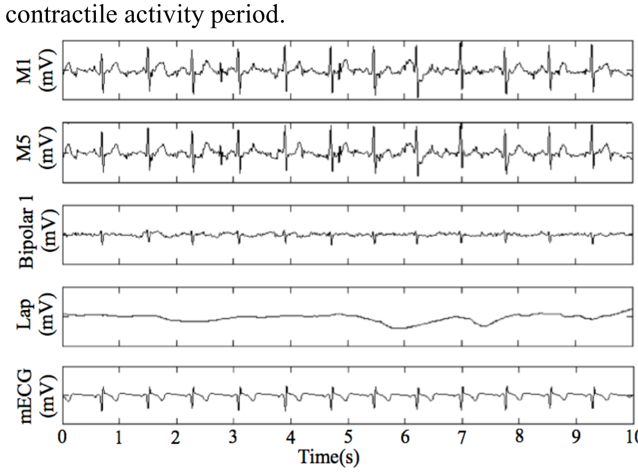

Fig 2. Signals (descending order): M1: monopolar 1, M5: monopolar 5, B1: Bipolar1, Lap: active concentric ring laplacian, mECG: Maternal ECG.

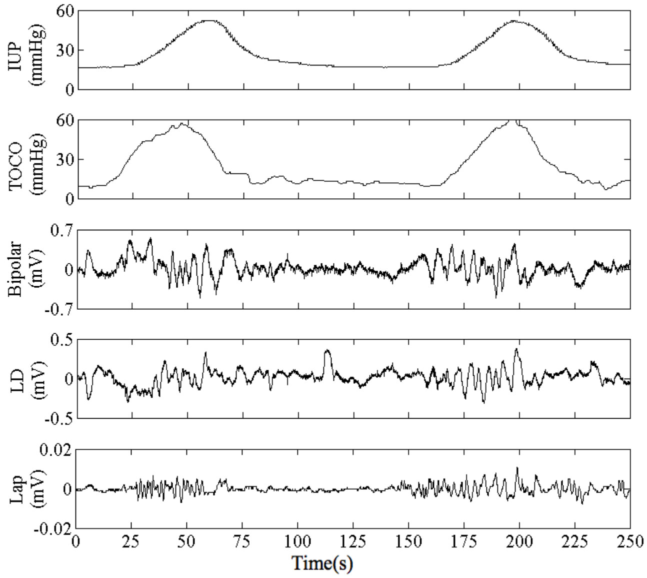

Fig. 3. Signals (descending order): IUP (intrauterine pressure), TOCO (Tocodynamometer), Bipolar (B_3), LD (discrete laplacian), Lap (laplacian potential using ringed-electrode).

It should be clarified that in order to compare the discrete laplacian potential amplitude estimated from the five monopolar electrodes with the recorded using ringed-electrodes, both laplacian potentials were expressed in mV instead of in mV/cm^2. This figure shows that a uterine contraction is associated to a pressure rise in IUP and TOCO recordings and to a burst, i.e. rise of amplitude and frequency, in the different EHG recordings. The detected contractions coincide in time with patient's pain symptoms. Contractions' duration is around 60 seconds and amplitude is about ±1mV in bipolar recordings which agrees the literature [3].

However, not all the contractions could be detected by the 3 different monitoring techniques (IUP, TOCO and EHG) tested in this work. The number of contractions identified in each recording technique and the CCI that values the consistency of the contractions detected by TOCO and by the different EHG recordings in comparison to IUP, is shown in table I.

The IUP detected a total of 127 contractions, whereas only 98 contractions were detected by the tocodynamometer. On the other hand, bipolar 1 and active concentric ring laplacian 1 were the EHG recording channels that detected most uterine contractions; 113 and 112 respectively.

The number of contractions detected and the contractions consistency index in TOCO are minor than IUP. The literature has reported that TOCO is a limited method that does not provide accurate information about the parameters of interest in monitoring uterine dynamics, such as intensity and contraction duration [2]. Moreover, there is not a standard placement for TOCO transducer and some uterine contractions can be missed. Figure 4 shows 250 seconds of signals during recording session 3. In this period TOCO does not detect two uterine contractions that are easily identified in IUP and EHG recordings. This failure may be due to poor positioning of the TOCO transducer.

On the other hand, IUP which is considered to be the gold standard to monitor uterine contractions may also miss some contractions and this also affects CCI. Figure 5 shows that in this period of session 1, IUP fails to detect a contraction that can be identified both in TOCO and EHG recordings between seconds 250 and 400. This can probably be because EHG recordings can be more sensitive to local contractions of minor amplitude than IUP.

Regarding the results of EHG recordings, the difference between the number of contractions identified and CCI by bipolar 1 and bipolar 4 is probably due to electrodes location. Electrodes associated to bipolar 1 signal are located on the lower vertical median line of the abdomen, in particular on the region immediately below the umbilicus, where according to [8] the highest SNR is obtained, whereas electrodes of bipolar 4 signal are placed on the horizontal line. The discrete laplacian (LD) presents slightly better results than the worst bipolar channel, probably because it has lineal dependency with the four bipolar recordings. Finally, it should be highlighted that the signals from concentric ring electrodes (L1 and L2) present better results than TOCO and similar results to bipolar 1. Considering ringed electrodes location, the results of laplacian

TABLE I: NUMBER OF DETECTED CONTRACTIONS (DC) AND CCI FOR EACH RECORDING SESSION AND GLOBAL RESULTS

Session	Time (min)	Param	IUP	TOCO	B1	B2	B3	B4	L1	L2	LD
1	120	DC	41	35	38	36	36	36	38	39	36
		CCI	-	92%	96%	94%	94%	94%	96%	98%	94%
2	38	DC.	11	6	11	6	10	9	10	8	8
		CCI	-	57%	85%	67%	91%	86%	80%	73%	70%
3	107	DC.	33	18	30	28	30	26	32	26	22
		CCI	-	67%	94%	83%	92%	87%	96%	87%	79%
4	63	DC	21	18	15	9	15	8	14	11	11
		CCI	-	84%	75%	55%	79%	50%	78%	65%	65%
5	70	DC	21	21	19	18	10	2	18	18	13
		CCI	-	100%	95%	92%	65%	17%	92%	92%	76%
Global	398	DC.	127	98	113	93	101	81	112	102	90
		CCI	-	83%	91%	83%	87%	76%	91%	87%	80%

* IUP (intrauterine pressure), TOCO (Tocodynamometer), B_i (Bipolar), L1 and L2 (laplacian potential using ringed electrodes), LD (discrete laplacian).

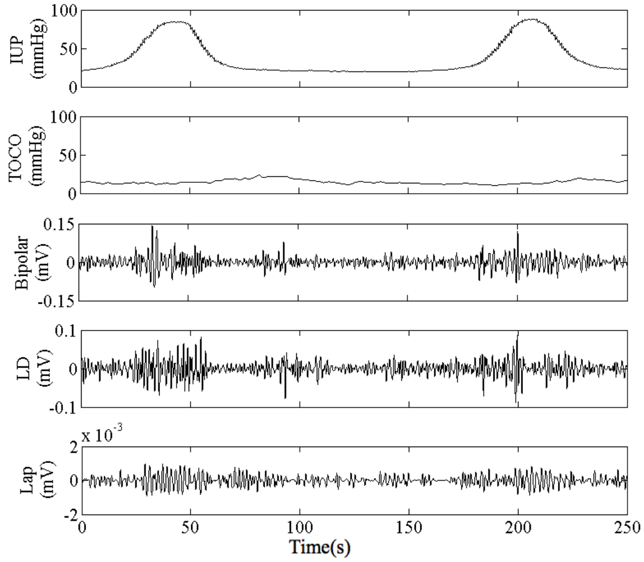

Fig 4: Signals (descending order): IUP (intrauterine pressure), TOCO (Tocodynamometer), Bipolar (B_3), LD (discrete laplacian), Lap (laplacian potential using active concentric rings). TOCO fails to detect two contractions between seconds 0 – 250.

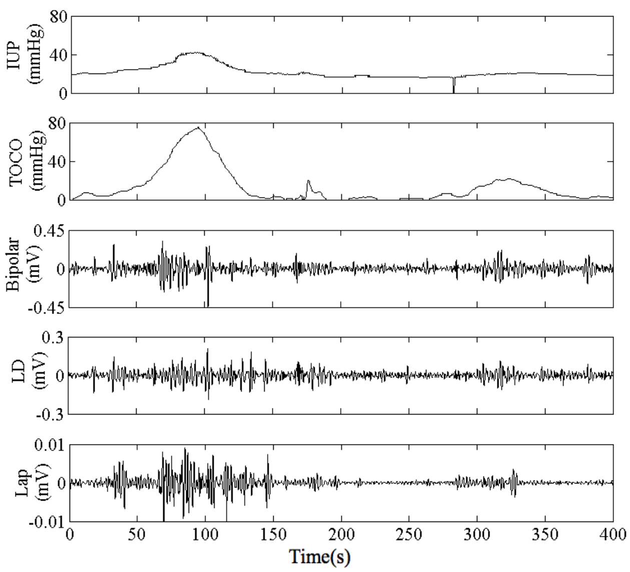

Fig 5: Signals (descending order): IUP (intrauterine pressure), TOCO (Tocodynamometer), Bipolar (B_1), LD (discrete laplacian), Lap (laplacian potential using active concentric rings). IUP fails to detect a contraction between seconds 250 – 400

recordings could even be better if these electrodes were placed immediately below the umbilicus.

Euliano *et al* also calculated the CCI between TOCO and IUP, and between bipolar recordings of EHG with IUP [7]. In that study they obtained similar results (94% for EHG, and 88% for TOCO) to those obtained in the present work. However the conditions to consider that the detected contractions are consistent are less severe in Euliano's work. Precisely, they consider that contractions were consistent when the peak of a contraction from the EHG signal was within plus or minus 1 minute of the peak of a contraction from the IUP [7]. In this study we considered a 10-seconds-interval between peaks of contractions detected in EHG and IUP signal. Although wider time intervals can yield higher CCI values, we consider that this condition is more realistic according to physiological conditions and propagation velocity of contractions.

This is the first time ringed electrodes are successfully used to record the laplacian potential of EGG signal and to non-invasively detect uterine contractions. In respect to this, it should be mentioned that Li *et al.* published a work about the design of an active laplacian electrode for EHG recordings [9]. However, the signals recorded by that electrode were not shown in that paper and, to the authors' knowledge, subsequent studies on this issue have not been reported.

IV. Conclusion

Our results suggest that EHG recordings are more reliable to identify uterine contractions that tocodynamometers (TOCO). Laplacian recordings of EHG by means of active-ringed-electrodes are less affected by cardiac interference while keeping reliability to detect uterine contractions. Nevertheless a more comprehensive database should be analyzed to corroborate the results of this work.

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