Abdominal EHG on a 4 by 4 grid: mapping and presenting the propagation of uterine contractions

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Abstract— **Numerous studies have observed and analyzed the external electrical activity of the uterus associated with contractions and labor. Most of these studies have involved the use of only 3 to 5 electrodes and little effort has been made to investigate the electrical activity concurrently at different locations. In this paper we present the results from measurements of contractions in labor using a 16 electrodes grid. We tried out various methods of presenting and analyzing this data and found this to be a non-trivial task. Here we present both an animation of the evolution of the electric potential, as well as a temporal correlation presentation. The results from a limited sample are in many ways surprising and may provide a new insight in to possible mechanism underlying uterine contractions.**

Keywords— **EHG, labor, uterus, mapping, propagation**

I. Introduction

Premature labor is one of the most important public health problems in Europe and other developed country as it represents nearly 7% of all births. It is the main cause of morbidity and mortality of newborns. Early detection of a preterm labor is important for its prevention for example in insuring tocolytic drug efficacy. Continuous efforts are made to find new biochemical or biophysical markers of preterm labor threat [1]. One of most promising is the analysis of the electrical activity of the uterus. Uterine electromyogram recorded externally in women, the so called electrohysterogram (EHG), has been proved to be representative of uterine contractility. The analysis of such signal may allow the prediction of a preterm labor threat as soon as 28 weeks of gestation (WG) [2-4]. However, the physiological phenomena underlying preterm labor remain badly understood. It is well known that the uterine contractility depends on the excitability of uterine myocytes but also on the propagation capability of local electrical activity to the whole uterus [5]. These two aspects of uterine contractions mechanisms, excitability and propagation, both influence the spectral content of EHG.

EHG is mainly composed of two frequency components traditionally referred to as FWL (Fast Wave Low) and FWH (Fast Wave High) [5]. These frequency components may be related to the propagation and the excitability of the uterus respectively. Recent studies on the early prediction of preterm labor focused on the analysis of FWH or simply the high frequencies of the EHG. If the above hypothesis of FWH being primarily related to the local excitability of the uterus is correct, the mechanisms of coordination and organization of the uterus as a whole has still not been fully understood or exploited in predicting labor.

The propagation of the electrical activity of the uterus has been studied both at a cellular level and on the organ as a whole. The propagation at a cellular level shows complex activation pathways with the possible presence of multiple fronts or re-entry like in the heart [6]. Investigation of the propagation at the organ level has only been done using 3 to 5 recording electrodes. The propagation speed observed is very dependent on the species but the average estimated speed was typically superior to 2 cm/s as reported by [7, 8] for example. Planque describes a speed, calculated on abdominal EHG recorded in woman, of 2.18 cm/s and of a propagation in a descending direction in 87% of cases [9]. Duchêne et al. also noticed a constant chronogram of the activation pattern during labor in monkeys [10].

The main method of EHG propagation analysis has so far been linear intercorrelation. In reported work the intercorrelation coefficients calculated on EHG envelope are usually good (~80%) but the coefficients calculated on temporal signals are much lower. This could depict a good group propagation (sequential activations of several uterine regions) but not a strict linear propagation between each recording regions as frequently observed in striated muscles. Other more sophisticated analysis tools have been used but were unable to properly demonstrate linear propagation [9-11].

The aim of this paper is to study the propagation of the uterine electrical activity recorded on women during labor. We present a specific recording methodology using 16 monopolar electrodes and the results of preliminary measurements. We show examples and group propagation analysis tools.

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II. Materials and methods

A. Instrumentation and experimental protocol

The measurements were performed by using a 16-channel multi-purpose physiological signal recorder most commonly used for investigating sleep disorders (Embla A10). Reusable Ag/AgCl electrodes were used. The measurements were performed at the Landspitali University hospital in Iceland using a protocol approved by the relevant ethical committee (VSN 02-0006-V2). The subjects were healthy women in the first stages of labor having uneventful singleton pregnancies.

After obtaining informed consent, the skin was carefully prepared using an abrasive paste and alcoholic solution. After that, the sixteen electrodes were placed on the abdominal wall according to Fig. 1 (interelectrode distance: 2.1 cm). The third electrode column was always put on the uterine median axis and the 10-11th electrode pair on the middle of the uterus (fundus to symphysis). Reference electrodes were placed on each hip of the woman. The signal sampling rate was 200 Hz. The recording device has an anti-aliasing filter with a high cut-off frequency of 100 Hz. The tocodynamometer paper trace was digitalized in order to facilitate the segmentation of the contractions.

In this preliminary study, two women in spontaneous labor were enrolled at 37 and 39 WG. The recording duration was approximately 1 hour in both cases. 23 and 21 contractions were clearly identified on these. In our study, we considered vertical bipolar signals (BP_i) in order to increase the signal to noise ratio. Our signals form thus a rectangular matrix of size 3 x 4. All the EHG bursts presented a good signal to noise ratio on all of the bipolar channels. All the EHG bursts were segmented manually with the help of the tocodynamometer trace.

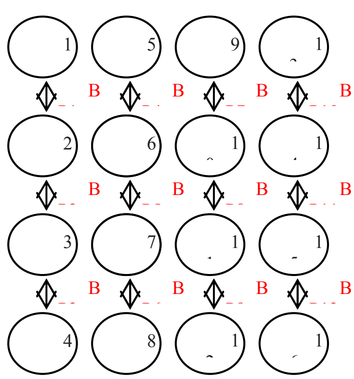

Fig. 1: Electrode configuration on the woman abdominal wall and position of bipolar signals Bpi.

B. Signal processing and animation tools

After a manual segmentation of each contraction, the envelope of each bipolar EHG signal was calculated. The envelope was defined as the modulus of the analytical signal obtained by Hilbert transform. The different envelopes were then filtered by a moving average filter.

Propagation animation: This involved representating the evolution of the envelope amplitude on each bipolar signal as a function of time. For each time n, the envelope amplitude was display in an arbitrary color scale. All amplitudes were normalized by the maximal amplitude obtained for each of the different channels. In order to obtain a smoother representation, the 3 x 4 amplitude matrix was interpolated to 9 x 13. To facilitate the interpretation of such representation, the gradient information (amplitude and angle) was superimposed.

Correlation analysis: The most common way to analyze the delay between two signals, $x(n)$ and $y(n)$, is the use of the intercorrelation function $Ø(k)$. This function presents a maxima for a value K_0 corresponding to the delay T_0 between the two signals. The maxima position gives information on the delay but also on the propagation direction. We could have three distinct situations:

- If $0 < K_0 < (N/2+1)$, then $x(n)$ is in advance of:
  $T_0 = K_0/F_s$ seconds on $y(n)$
- If $(N/2) < K_0 < N$ then $y(n)$ is in advance of:
  $T_0 = (N - K_0)/F_s$ seconds on $x(n)$
- If $K_0 = 0$ then $x(n)$ and $y(n)$ appeared simultaneously

Where F_s is the sampling frequency and N the length of each signal. The intercorrelation function can be obtain by the Fourier transform (FT) of each signal. The FT of the intercorrelation function is then:

$$\Phi(f) = X(f)Y^*(f)$$

Where $X(f)$ and $Y(f)$ are the FT of $x(n)$ and $y(n)$ respectively and * indicates complex conjugate.

The intercorrelation function is then obtained by inverse Fourier transform. A normalization of $Ø(k)$ by the energy of the two signals guaranties that this function is bounded between 0 and 1.

All delays were calculated with the envelope of BP_8 as reference signal $x(n)$. The delay matrix were interpolated linearly in order to obtain a smoother representation.

III. Results

A. Envelope amplitude animation

The observation of the temporal animation of the envelope amplitude is realized by the interface presented Fig. 2. This interface shows the tocodynamometer trace, the mean EHG envelope and the envelope amplitude for each channel spatially.

These animated maps of uterine electrical activity show a surprising amount of structure. At each location (electrode pair) several bursts of activity can be observed at different times in each contraction as the potential sweeps across the uterus.

The animations are very complex to analyze. We have however been able to notice some particular situations. It is possible at times to observe ascendant activation patterns while for the majority of the contractions the activation patterns is descendant. In this situation, the uterine activity begins at the lower electrodes or those situated on one side and then propagate to the other electrodes. Several origins of the activity could often be observed (Fig. 3). Some of the individual envelopes do not present their maximal value at the maximal amplitude of the mean EHG envelope (Fig. 4). The maximum of the EHG envelopes are usually observed close to the maximum of the tocodynamometric trace but are not synchronized to each other. It indicates that, even in labor, a delay between each channel is observed. Moreover, rotating activation patterns have been noticed during the same contraction. For one contraction, the presence of a pace-maker-like node that apparently initiated the whole contraction was observed in that the electrical activity begins on one EHG channel then propagates to other channels.

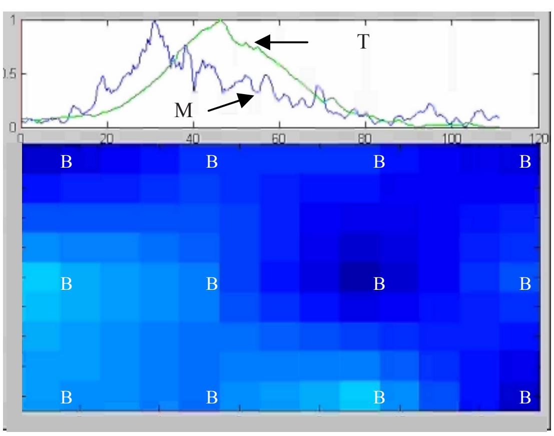

Fig. 2: Visualization interface of the evolution of the envelope amplitude of each EHG channel (BP1 to BP12). The upper trace represents the normalized tocodynamometer trace (Toco.) and the normalized mean envelope (MEnv.) calculated on each channel (x axis in second).

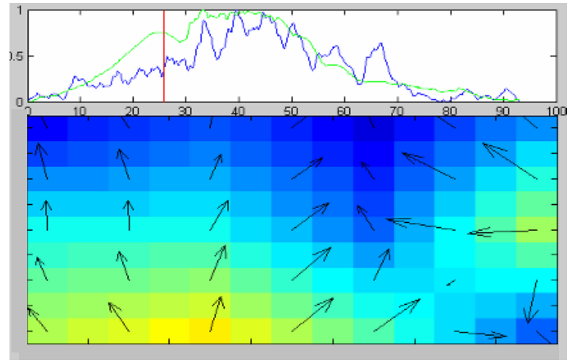

Fig. 3: Example of the presence of several origins of the activity and ascendant activation pattern. The gradient information is indicated by arrows.

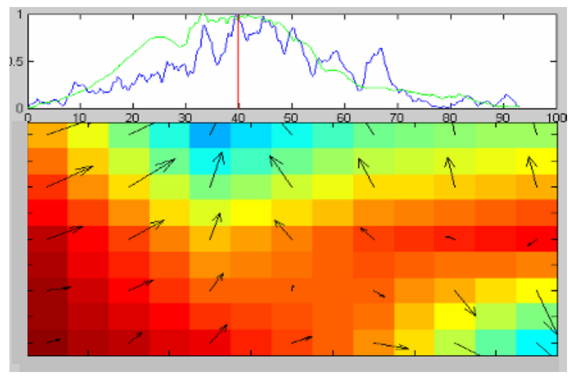

Fig. 4: Envelope amplitudes obtained at the maximal value of the mean envelope. The gradient information is indicated by arrows.

Several animations can be found at http://www.ru.is/brynjar/ehg.

B. Correlation analysis

The correlation analysis gives information on the global delay between all EHG channels during a contraction. The quality of the correlation between channels was also evaluated by calculating the correlation coefficients. This analysis permits to better reveal the presence of a pace-maker-like activity. A point of origin could be easily seen in Fig. 5, were an isolated area with a negative delay is observed. The corresponding correlation coefficient are relatively good indicating a true physiological phenomena (> 75 %).

IV. DISCUSSION

Our analysis of the evolution of the envelope amplitude during contraction showed a non linear propagation with complex activation patterns. Ascendant or rotating activation patterns were observed. It has been proposed that pace-maker cells are present preferentially near the uterine fundus [7]. It is however well known that all uterine cells can become a pace-maker cell. The electrical activity can thus be initiated anywhere on the uterus. The rotating pattern can be explained by re-entry phenomenon where the electrical activity returns to its initiation site after a certain time. This interpretation is unfortunately only qualitative as of yet. A more detailed characterization of the activation patterns has to be done in order to observe how it evolves as the uterus organizes itself from the quiet state during most of the pregnancy to the very active coordinated state during the final stages of labor. Intercorrelation analysis of the EHG envelopes is an example of how quantitative information can be extracted from this type of data. It indicates the global delays between the electrical burst present on each recording channel. The quality of the parameter can also be checked by the different correlation coefficients, providing a new way of identifying effective contractions. The study of the different delays obtained for one contraction reveals clearly the presence of a pace-maker-like initiator cells under the electrodes. We have not observed a constant chronogram or activation pattern for successive contractions like reported by [10]. However, in our study, the inter-electrode distance is shorter and thus could reflect a more local propagation pattern. Other correlation analysis tools have to be evaluated in order to extend our preliminary results and maybe to increase the accuracy of our analysis. For example, the linear correlation coefficients calculated on temporal EHG were very low [9], the use of non-linear correlation techniques may be more suitable for this signal. An other important perspective of this work is the confirmation or the rejection of the hypothesis, stated by Devedeux et al [5], on the link between FWL and the propagation on one hand and FWH and excitability on the other hand. Analysis of the correlation of the energy of each frequency component separately could answer this open question.

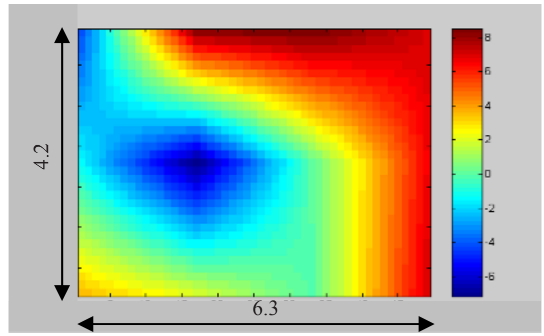

Fig. 5: Estimated delays (second) obtained, for one contraction, by intercorrelation. A higher interpolation was realized to increase the readability.

V. CONCLUSIONS

In this paper, we present a recording for device with 16 monopolar electrodes. The possibility of a mapping the electrical activity of the uterus is likely to give new information on the propagation of activity in the organ. The animation of the spatial and temporal evolution of the energy of the 12 bipolar EHG permitted us to observe complex activation patterns. These animations and the use of EHG intercorrelation mapping may also show the presence of pace-maker activity or re-entry like those observed in the heart. Our methodology may eventually help to characterize various obstetrical situations and even provide tools useful in managing preterm labor.

REFERENCES

1. J. Terrien, C. Marque, and G. Germain, "What is the future of tocolysis?," *Eur J Obstet Gynecol Reprod Biol*, vol. 117 Suppl 1, pp. S10-4, 2004.
2. H. Leman, C. Marque, and J. Gondry, "Use of the electrohysterogram signal for characterization of contractions during pregnancy," *IEEE Trans Biomed Eng*, vol. 46, pp. 1222-9, 1999.
3. R. E. Garfield, H. Maul, L. Shi, W. Maner, C. Fittkow, G. Olsen, and G. R. Saade, "Methods and devices for the management of term and preterm labor," *Ann N Y Acad Sci*, vol. 943, pp. 203-24, 2001.
4. R. E. Garfield, H. Maul, W. Maner, C. Fittkow, G. Olson, L. Shi, and G. R. Saade, "Uterine electromyography and light-induced fluorescence in the management of term and preterm labor," *J Soc Gynecol Investig*, vol. 9, pp. 265-75, 2002.
5. D. Devedeux, C. Marque, S. Mansour, G. Germain, and J. Duchene, "Uterine electromyography: a critical review," *Am J Obstet Gynecol*, vol. 169, pp. 1636-53, 1993.
6. W. J. Lammers, "Circulating excitations and re-entry in the pregnant uterus," *Pflugers Arch*, vol. 433, pp. 287-93, 1997.
7. R. Caldeyro-barcia and J. J. Poseiro, "Physiology of the uterine contraction," *Clin. Obstet. Gynecol.*, vol. 3, pp. 386-408, 1960.
8. E. E. Daniel and S. A. Renner, "Effect of the placenta on the electrical activity of the cat uterus in vivo and in vitro," *Am J Obstet Gynecol*, vol. 80, pp. 229-44, 1960.
9. S. Planque, "Contribution a l'etude de la propagation des signaux electrohysterographiques," in *Genie biomedical*. Compiegne: Universite de technologie de Compiegne, 1990.

10. J. Duchene, C. Marque, and S. Planque, "Uterine EMG signal: Propagation analysis," presented at Annual International Conference of the IEEE EMBS, 1990.
11. S. Mansour, "Etude de l'electromyographie uterine : caracterisation, propagation, modelisation des transferts," in *Génie biomedical*. Compiegne: Universite de technologie de Compiegne, 1993.

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