31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

# Spatial analysis of uterine EMG signals: evidence of increased in synchronization with term

Hassan M., Terrien J., Karlsson B. and Marque C.

*Abstract*—**Evaluation of synchronization between signals can give new insights into the functioning of the related systems. Methods that can detect synchronization or coupling between signals can be divided two types: linear and non linear methods. In this paper we use the non linear correlation coefficient ($h^2$) to show the difference in synchronization between efficient uterine contractions during labor and normal physiological contractions during pregnancy, in uterine activity bursts recorded at different places on the pregnant abdomen. Our interest in the non linear correlation coefficient is based on the fact that the propagation mechanism of uterine EMG signal may be strongly non linear. The results obtained from estimating the synchronization between 16 uterine EMG channels indicate that synchronization between contractions as measured by $h^2$ is stronger in labor than in pregnancy. Limited data indicates that the $h^2$ value increases markedly with term when expressed in duration before spontaneous labor.**

## I. INTRODUCTION

RELATIONS between time series can be estimated using several methods. Methods proposed so far can be divided into two types depending on the underlying suppositions of dependence between signals. Linear methods include for example the linear cross-correlation or the coherence function. These methods are efficient but rely on the assumption of linear dependence between the investigated signals. In many real biological cases however, the relationship between two signals has non linear characteristics. Uterine EMG signals present a largely non linear behavior as shown in [1].

The development of non linear methods is more recent [2]. Mars et al. were the first who applied methods based on mutual information on the EEG signals to determinate relationships and time delays between simultaneously recorded EEG signals during an epileptic paroxysm [3]. Pijn et al. also used non linear regression in EEG analysis [4].

This study was supported by the Icelandic center for research RANNIS.

M. Hassan and C. Marque are with the Université de Technologie de Compiègne – CNRS UMR 6600 Biomécanique et Bio-ingénierie, F60205 Compiègne Cedex, France. (corresponding author: +33 3 44 23 44 23 (4844); fax: +33 3 44 23 79 04 ; e-mail : mahmoud.hassan@utc.fr).

M. Hassan, J. Terrien and B. Karlsson are with the School of Science and Engineering, Reykjavik University, Reykjavik, 103 Iceland.

B. Karlsson is with the department of physiology, University of Iceland, Reykjavik, Iceland.

Finally, methods coming from non linear physics (non linear dynamical systems) and chaos theory have been applied to investigate non linear coherence between biological signals [5].

The above methods have been widely applied to EEG signals in research and for clinical purposes. The electrohysterogram (EHG) is the signal associated with the action potentials propagating through smooth muscle cells of the uterine muscle (myometrium) to the abdomen of pregnant women. Methods detecting synchronization of EHG are beginning to show encouraging results. Terrien et al., using a pre-segmentation method, applied non linear regression and phase synchronization methods to study the dependence between non stationary signals like uterine EMG signals. The results on signals recorded from a monkey during labor indicated a marked increase in the parameter $h^2$ inside the contractile event as compared to baseline $h^2$ values [6].

In this paper we study the coupling between the different EHG signals acquired by means of a 4 x 4 matrix of electrodes on the surface of the abdomen of pregnant women, in order to gain insight into what is happening in the uterus muscle below the electrodes. We use the non linear regression coefficient ($h^2$) to evaluate the synchronization between geometrically separate uterine activities bursts. The difference between the matrices of $h^2$ calculated between different electrodes during labor and during pregnancy is shown, and then the evolution of $h^2$ during term, on a limited dataset.

## II. MATERIALS AND METHODS

### *A. Data*

We studied 11 women: 5 recorded during pregnancy (33-39 week of gestation, WG) and 6 during labor (39-42 week of gestation, WG). After manual segmentation of EHG bursts, with the help of the tocodynamometer trace, we obtained 22 labor contractions and 35 pregnancy contractions. The measurements were made at the Landspitali University hospital in Iceland and FSA Akureyri, Iceland, using a protocol approved by the relevant ethical committee (VSN 02-0006-V2). The measurements were performed using a 16 electrode grid, arranged in a 4x4 matrix, positioned on the woman's abdomen (Fig. 1). In this study, we considered vertical bipolar signals (Vbi) in order to increase the signal to noise ratio. Our signals form thus a rectangular 3 x 4 matrix. All the EHG bursts presented a good signal to noise ratio on all bipolar channels. Signals were sampled at 200 Hz. The recording device has an anti-aliasing filter with a high cut-off frequency of 100 Hz. The simultaneous tocodynamometer paper trace was digitalized to ease the segmentation of the EHG bursts.

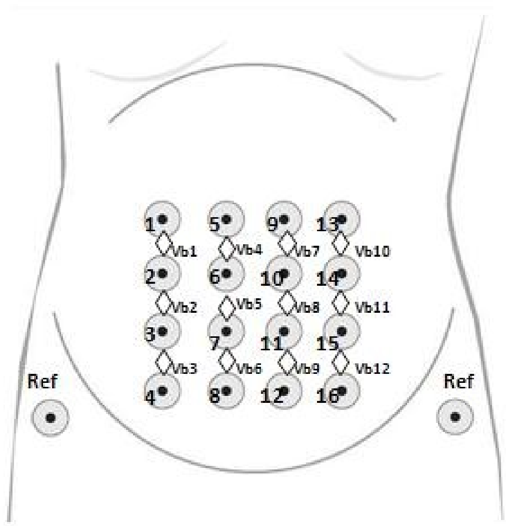


Fig. 1. Electrode configuration on the woman's abdominal wall. Vbi represent the derived bipolar signals.

### B. Non linear correlation coefficient ($h^2$)

Non linear correlation analysis is a non-parametric method used for evaluating the dependency of a random process (a time-series $Y$ recorded from $G_Y$, for instance) on another process (signal $X$ recorded from $G_X$, for instance) and independently of the type of relationship between the two processes. Pijn and al. showed that this method performed better than methods based on linear regression for analyzing the interdependences between intracerebral EEG signals [7]. Wendling and al. showed that this method can be applied to human intracerebral EEG data for characterizing seizure patterns [8].

Kalitzin et al. confirmed the usefulness of the $h^2$ parameter in the quantification of the statistical relationships between random signals [9]. More recently, a robustness study has shown the evolution of $h^2$ between: pre-ictal period→seizure onset→seizure termination on EEG signals [10].

Non linear regression analysis is a bivariate method that estimates the degree of dependence between two variables. The non linear correlation coefficient $h^2$ is computed from the signals *X (t)* and *Y (t)*, by considering that the value of *X* is seen as a function of the value of *Y*. The value of *Y*, given *X*, can be predicted according to a non linear regression curve. The variance of *Y* according to this regression curve is termed as the explained variance, since it is explained or predicted by the knowledge of *X*. The unexplained variance is estimated by subtracting the explained variance from the original one. The correlation ratio $h^2$ describes the reduction of variance of *Y* that can be obtained by predicting the *Y* values from those of *X* according to the regression curve as $h^2$ = (total variance - unexplained variance)/total variance.

In practice, to estimate the non linear correlation coefficient ($h^2$), a scatter plot of *Y* versus *X* is studied. The values of *X* are subdivided into bins; for each bin we calculate, the *X* value of the midpoint ($p_i$) and the average value of *Y* ($q_i$) computed from the same bin interval. The regression curve is approximated by connecting the resulting points ($p_i$, $q_i$) by straight line segments [11]. Then, the non linear correlation coefficient between the two signals *X* and *Y* is calculated as follows:

$$h^2_{Y/X} = \frac{\sum_{k=1}^{N} X(k)^2 - \sum_{k=1}^{N} (Y(k) - f(X_i))^2}{\sum_{k=1}^{N} Y(k)^2}$$

where $f(X_i)$ is the linear piecewise approximation of the non linear regression curve. The values of $h^2$ are between 0 (*X* and *Y* are independent) and 1 (*Y* is determined by *X*). One of the advantages of the non linear regression is that it can be applied to signals independently of whether their relationship is linear or not. Another interesting property of the non linear correlation coefficient $h^2$ is that it is asymmetrical: the $h^2$ value, from signal *X* to signal *Y*, differs from the value from signal *Y* to *X*. Wendling et al. used this property and proposed a new parameter named "direction index" to show the direction of the dependency between *X* and *Y* [8].

## III. RESULTS

The $h^2$ values were computed pair wise (144 possible pairs for the 12 bipolar signals recorded on the woman's abdomen). We chose to represent them in color-coded non linear correlation matrices. One correlation matrix represents therefore all the information concerning the $h^2$ values for the relevant contraction. When the aim is to compare two classes of contraction (pregnancy, labor), the mean of $h^2$ is plotted for each class as to obtain values that are representatives of each class. We first compute the mean of $h^2$ over the matrix related to each contraction studied, then the mean of these values over all the contractions associated to each class.

An example of results obtained is illustrated in (Fig. 2). This figure presents two $h^2$ matrices obtained from two different EHG: one recorded during a pregnancy contraction (Fig. 2a) and one during a labor contraction (Fig. 2b). The $h^2$ matrices indicate low values over almost all the channels (mean = 0.2±0.05, Fig. 2c) for the pregnancy contraction and high values (mean = 0.57±0.1) for the labor contraction.

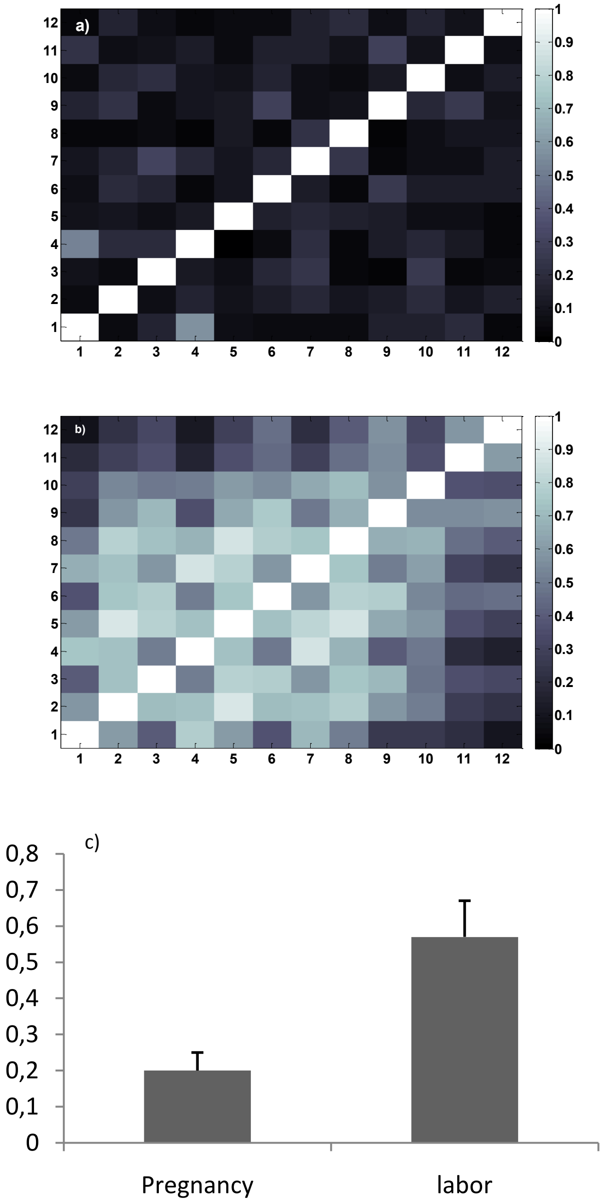


Fig. 2. a) The $h^2$ matrix corresponding to a pregnancy contraction (32 WG) b) The $h^2$ matrix corresponding to a labor contraction (41 WG) c) The average of $h^2$ over all the channels for each matrix.

We also observed that $h^2$ values can exhibit a longitudinal evolution along gestation. Fig. 3 presents the evolution of $h^2$ computed from data recorded at three increasing pregnancy terms for one given woman. We compute $h^2$ and then the average over all the contractions observed during these three recording sessions: 4 contractions at 33 WG (G1), 2 contractions at 35 WG (G2) and 3 contractions at 37 WG (G3). Fig.3 evidences noticeable modifications of $h^2$ values (interpreted as couplings between channels) occurring along term (Fig.3.a: 33WG 3.b:35WG 3c: 37WG).

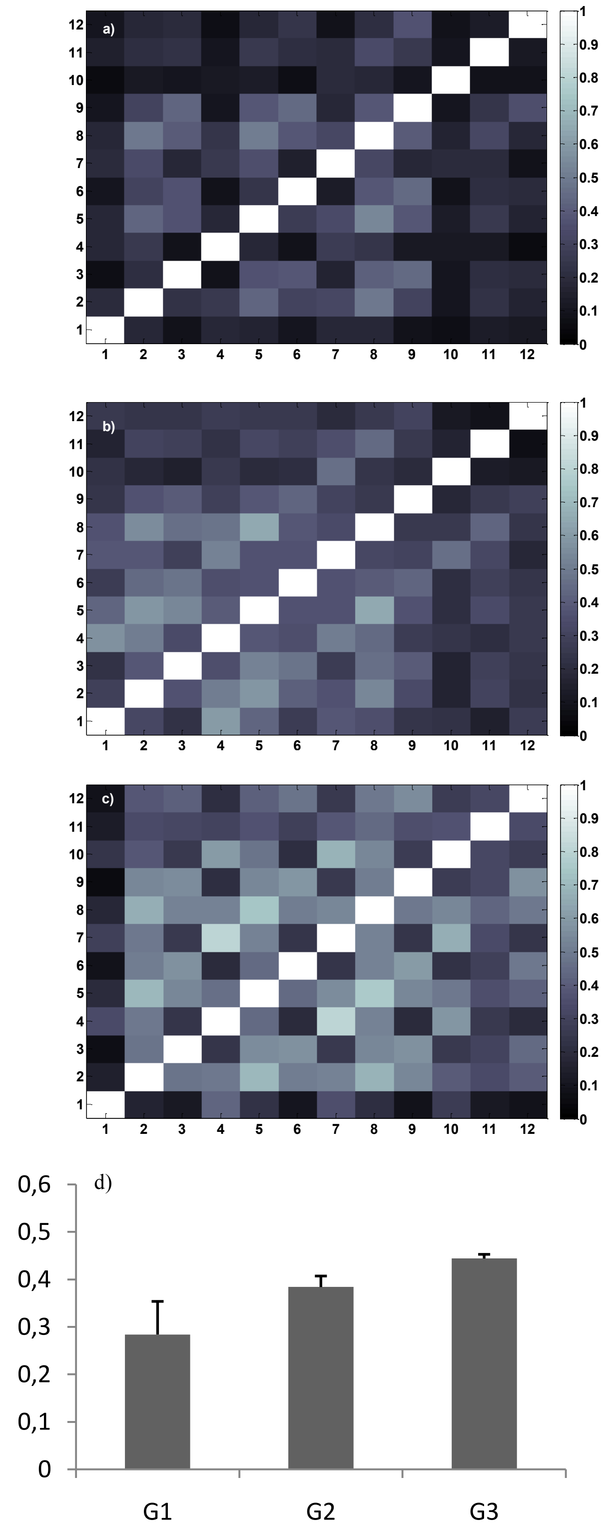


Fig. 3. The evolution of the $h^2$ matrix along term for a given woman a) G1: 33WG b) G2: 35WG c) G3: 37WG d) mean of $h^2$ at each term.

Then we calculated the average of $h^2$ matrix at each pregnancy term. The results indicate that the values of the non linear correlation coefficient increase with the term (Fig.3.d). The mean values evolve from 0.27 (at 33 WG) to 0.44 (at 37 WG). In particular, a strong increase in $h^2$ values is observed from 0.27 at "33 WG" to 0.38 at "35 WG".

## IV. DISCUSSION

Several methods can be proposed to study the relation between biological signals. The functional coupling between two systems can be quantified by computing the statistical relationship between two signals generated by these systems. This relation was denoted by various names like "correlation", "synchronization", "interdependency" or "coupling" between signals.

Our study of this relation in uterine activity indicates that a difference exists between the values of the non linear correlation coefficient in pregnancy and labor, associated with an increase in $h^2$ with term. The ultimate goal of this work is to find a method that can be used for the prediction of premature labor.

As of now, we only have longitudinal data for two women and for one of the women we only have two data points. The evidences provided by this scanty dataset are far from being a conclusive evidence of this evolution along term. It does not neither permit us to give a quantitative value for this increase. However the results obtained for available signals recorded from these two women (Fig. 4) both indicate an increase in $h^2$ with term, when term is computed in weeks before labor. The absolute value of $h^2$ is however very different in these two cases. We are currently acquiring more data of this type to confirm this effect and to get a more reliable quantification of the $h^2$ evolution along term.

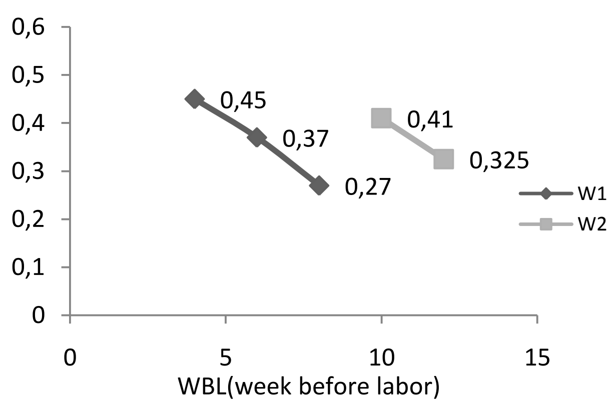


Fig. 4. The evolution of $h^2$ with week before labor for two women (W1 and W2).

## V. CONCLUSION

In this study we investigated the spatial synchronization between uterine electrical activities using non linear regression analysis. The $h^2$ matrices permitted to evidence a difference of coupling between labor and pregnancy contractions. The $h^2$ matrix also permitted to evidence an increase in the degree of synchronization between contractions along term. This information may be useful in clinical application to predict preterm deliveries.

## ACKNOWLEDGMENT

We are indebted to Mr. Ásgeir Alexandersson for his help in the acquisition of EHG signals.

## REFERENCES

[1] N. Radhakrishnan, J. D. Wilson, C. Lowery, P. Murphy, and H. Eswaran, "Testing for non linearity of the contraction segments in uterine electromyography," *International Journal of Bifurcation and Chaos,* vol. 10, pp. 2785-2790, 2000.

[2] R. M. Pikovsky A. , Kurths J., "Synchronisation : a universal concept in non linear sciences," in *Cambridge University Press* Cambridge, 2001.

[3] N. J. Mars and F. H. Lopes da Silva, "Propagation of seizure activity in kindled dogs," *Electroencephalogr Clin Neurophysiol,* vol. 56, pp. 194-209, Aug 1983.

[4] J. Pijn and F. Lopes Da Silva, " Basic Mechanisms of the EEG," in *Propagation of electrical activity: non linear associations and time delays between EEG signals* Boston: Zschocke & Speckmann, 1993.

[5] K. Lehnertz, G. Widman, R. Andrzejak, J. Arnhold, and C. E. Elger, "Is it possible to anticipate seizure onset by non-linear analysis of intracerebral EEG in human partial epilepsies?," *Rev Neurol (Paris),* vol. 155, pp. 454-6, Jul 1999.

[6] J. Terrien, M. Hassan, C. Marque, and B. Karlsson, "Use of piecewise stationary segmentation as a pre-treatment for synchronization measures," *Conf Proc IEEE Eng Med Biol Soc,* vol. 2008, pp. 2661-4, 2008.

[7] J. P. Pijn, D. N. Velis, and F. H. Lopes da Silva, "Measurement of interhemispheric time differences in generalised spike-and-wave," *Electroencephalogr Clin Neurophysiol,* vol. 83, pp. 169-71, Aug 1992.

[8] F. Wendling, F. Bartolomei, J. J. Bellanger, and P. Chauvel, "Interpretation of interdependencies in epileptic signals using a macroscopic physiological model of the EEG," *Clin Neurophysiol,* vol. 112, pp. 1201-18, Jul 2001.

[9] S. N. Kalitzin, J. Parra, D. N. Velis, and F. H. Lopes da Silva, "Quantification of unidirectional non linear associations between multidimensional signals," *IEEE Trans Biomed Eng,* vol. 54, pp. 454-61, Mar 2007.

[10] F. Wendling, F. Bartolomei, and L. Senhadji, "Spatial analysis of intracerebral electroencephalographic signals in the time and frequency domain: identification of epileptogenic networks in partial epilepsy," *Philos Transact A Math Phys Eng Sci,* vol. 367, pp. 297-316, Jan 28 2009.

[11] E. Pereda, R. Q. Quiroga, and J. Bhattacharya, "Non linear multivariate analysis of neurophysiological signals," *Progress in Neurobiology,* vol. 77, pp. 1-37, 2005/0 2005.