Wavelet phase synchronization between EHGs at different uterine sites: comparison of pregnancy and labor contractions

M. Hassan [1,2], Á. Alexandersson[3], J. Terrien[2], B. Karlsson [2,4] and C. Marque [1]

[1] Université de Technologie de Compiègne, CNRS UMR 6600, Biomechanics and Biomedical Engineering, Compiègne, France.
[2] School of Science and Engineering, Reykjavik University, Reykjavik, Iceland.
[3] Faculty of Medicine, University of Iceland, Reykjavik, Iceland.
[4] Department of physiology, University of Iceland, Reykjavik, Iceland.

Abstract– This study investigates phase synchronization in the time-frequency domain between uterine signals recorded at different sites during the same contraction from women during pregnancy and women in labor. We used the complex Morlet wavelet transform to estimate the phase synchronization between the uterine signals. The method was applied on a set of uterine bursts during pregnancy and in labor. The results indicated that the uterine bursts are more synchronized in phase during pregnancy than during labor. This phase desynchronization during labor may be a tool to differentiate between contractions during pregnancy and labor and could therefore be used in the prediction of preterm labor.

Keywords— **Uterine contraction; Wavelet phase synchronization; Preterm labor; EHG;**

INTRODUCTION

Electrohysterograms (EHG), or uterine electromyograms recorded externally on women, have been proven to be representative of uterine contractility. The analysis of these signals may allow the prediction of a preterm labor threat as soon as 28 weeks of gestation (WG) [1].

The study of signals dependency has become an important tool in understanding the function of the biological system. Numerous methods have been proposed to study signal interdependencies. They basically belong to two sets: linear methods (based on intercorrelation or coherence functions) and non-linear methods (based on non-linear regression, mutual information or comparison of phase trajectories in a state space built from signals). However, there is increasing interest in the use of wavelet-based techniques in processing non-stationary signals like EEG signals: investigating oscillatory behavior [2], spike detection [3] and filtering [4].

In this study we examine phase relationship between uterine electrical activities recorded at two different locations during the same contractions in order to differentiate between phase synchronization between signals during pregnancy and in labor.

Phase synchronization is a relationship between phases of two signals while their amplitudes may be uncorrelated. These facts differ the phase synchronization analysis from the coherence analysis because coherence, based on Fourier analysis, is highly dependent on stationarity of analyzed signals and, as a measure of spectral covariance, coherence does not separate effects of phase and amplitude [5].

In a previous study, we used "wavelet coherence" to detect the interaction between uterine electrical activities [6], but the wavelet coherence does not separate the effects of amplitude and phase in the dependency between two signals. Since we have already studied the amplitude correlation between uterine bursts by using the nonlinear correlation coefficient [7], we are interested in this study to investigate the phase relationship between uterine bursts.

The aim of this paper is to investigate the difference in phase synchronization between uterine contractions recorded from women during pregnancy and in labor. The uterine signals are recorded during the same contractions at different locations.

MATERIALS AND METHODS

A. Data

Real EHG signals used in this study were obtained from 3 women during pregnancy (30-32 week of gestation) and 3 women during labor. The measurements were obtained by using a 16 channel multi-purpose physiological signal recorder, most commonly used for investigating sleep disorders (Embla A10). We used reusable Ag/AgCl electrodes. The measurements were performed at the Landspitali University hospital in Iceland, following a protocol approved by the relevant ethical committee (VSN 02-0006-V2).

The signals used for this study were the bipolar signals Vb7 and Vb8 corresponding to two channels on the median vertical axis of the uterus (see [8] for more details). The signal sampling rate was 200 Hz. The recording device has

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an anti-aliasing filter with a low pass cut-off frequency of 100 Hz. The concurrent tocodynamometer (Toco) paper trace was digitized in order to ease the identification of contractions. The EHG signals were segmented manually to extract segments containing uterine activity bursts (Figure 1).

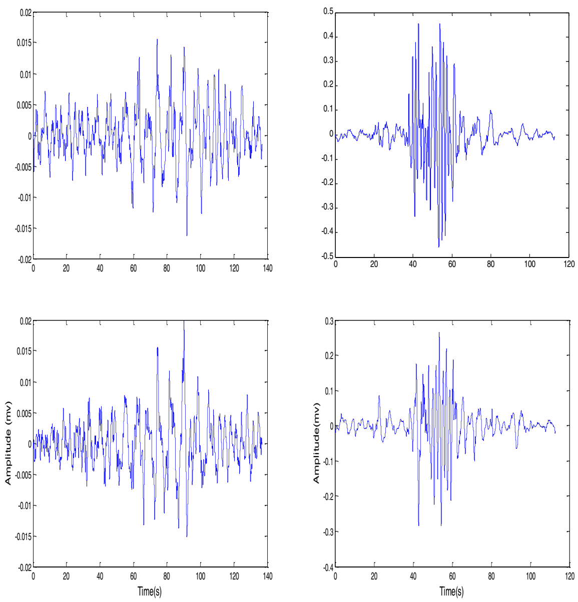

Fig. 1 Two uterine bursts recorded during the same contractions: pregnancy (left) and labor (right). Both represent Vb7 (top) and Vb8 (bottom) bipolar signals.

B. Wavelet transform

The continuous wavelet transform (CWT) can decompose a signal into a set of finite basis functions. Wavelet coefficients $W_x(a,\tau)$ are produced through the convolution of a mother wavelet function $\Psi(t)$ with the analyzed signal $x(t)$ or

$$W_x(a,\tau)=\frac{1}{\sqrt{a}}\int x(t)\Psi^*(\frac{t-\tau}{a})dt$$

where a and τ denote the scale and translation parameter; * denotes complex conjugation. By adjusting the scale a, a series of different frequency components in the signal can be extracted. The factor $\sqrt{a}$ is for energy normalization across the different scales. Through wavelet transforms, the information of the time series $x(t)$ is projected on the two dimension space (scale a and translation τ).

In this study, the Morlet wavelet was used, it is given by:

$$\psi_0(t)=\pi^{-1/4}e^{i\omega_0 t}e^{-\frac{1}{2}t^2}$$

where ω_0 is the wavelet central pulsation. In this paper we used ω_0=1. Morlet wavelet is a Gaussian–windowed complex sinusoid; the Gaussian's second order exponential decay of the Morlet function gives a good time localization in the time domain [9]. We chose the complex Morlet wavelet transform (MWT) as it provides the signal amplitude and phase simultaneously. This property allows us to use the MWT to investigate the coherence/synchronization between two signals recorded at two different sites.

C. Phase synchronization

The parameter used for measuring phase synchronization is the relative phase angle between two oscillatory systems.

The Morlet wavelet transform acts as a bandpass filter and, at the same time, yields separate values for the instantaneous amplitude A(t) and the phase Φ (t) of a time-series signal at a specific frequency. Thus, the wavelet phases of two signals X and Y can be used to determine their instantaneous phase difference in a given frequency band, and to establish a synchronization measure (Wavelet Phase Synchronization: WPS) which quantifies the coupling of phases independently from amplitude effects.

The principle of phase synchronization corresponds to a phase locking between two systems defined as:

$$\varphi_{n,m}(t)=\left|n\Phi_X(t)-m\Phi_Y(t)\right|\le C$$

where $\Phi_X(t)$ and $\Phi_Y(t)$ are the unwrapped phases of the signals of the two systems and C is a constant. For real noisy data the cyclic relative phase, $\varphi_{n,m}(t)$ mod 2π, is preferentially used. Note that according to the above equation, the phase difference has to be calculated from the univariate phase angle of each signal. Phase locking is observed if the phase difference remains approximately constant over some time period.

In order to evidence the variation of the strength of phase synchronization between two uterine segment bursts, we used the intensity of the first Fourier mode of the distribution, given by:

$$\gamma_{n,m}(t)=\sqrt{\langle\cos(\varphi_{n,m}(t))\rangle^2+\langle\sin(\varphi_{n,m}(t))\rangle^2}$$

where $\langle\ \rangle$ denote the average over time. The measure of synchronization strength varies from 0 (no phase synchronization) to 1 (perfect phase synchronization). It is also called the synchronization index. In this paper we use m=n=1.

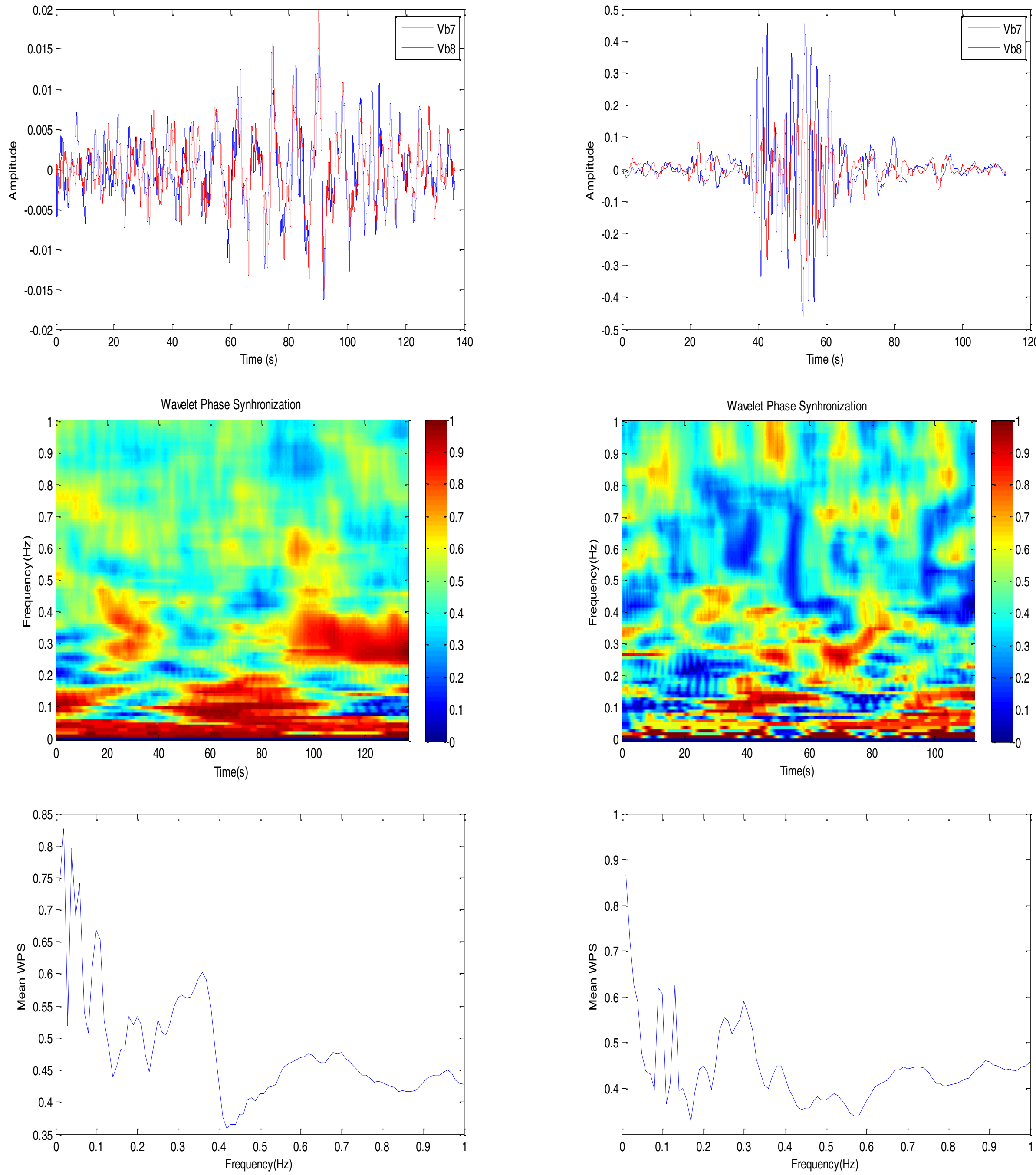

Fig. 2 (Top): Two uterine bursts (bipolar channels Vb7 and Vb8). (Middle): The phase synchronization between the two uterine bursts in the time-frequency plan. (Bottom): The mean of wavelet phase synchronization over frequency bands: pregnancy (left) and labor (right).

D. Results

The results (figure 2) indicate that higher phase synchronization is located at the lower frequencies in the case of labor and pregnancy and that phase synchronization during pregnancy is higher than during labor.

In order to find if this method can be a pertinent tool to classify pregnancy vs. labor bursts, we compute the mean of WPS at different frequency bands.

The results in table 1 correspond to 10 contractions (CTs) from 3 women during pregnancy (30-32 WG) and 10 contractions from 3 women during labor (delivery time of 39, 40 and 42 WG).

Table 1 indicates a kind of phase desynchronization from pregnancy to labor (notice that the values correspond to the frequencies between: 0-0.25 Hz).

Table 1 The mean of WPS between 10 contractions from 3 women during pregnancy and 10 contractions from 3 women in labor

CT #	Pregnancy	Labor
1	0,64±0.01	0,49±0.01
2	0,63±0.08	0,52±0.01
3	0,61±0.02	0,52±0.02
4	0,58±0.03	0,49±0.02
5	0,60±0.08	0,55±0.01
6	0,59±0.05	0,48±0.03
7	0,58±0.02	0,45±0.01
8	0,54±0.05	0,53±0.02
9	0,57±0.01	0,53±0.03
10	0,61±0.02	0,58±0.04
Mean	**0,595±0.02**	**0,514±0.03**

DISCUSSION

In this paper we have presented the first application of wavelet phase synchronization on EHG signals in order to detect relationships between uterine electrical activities recorded at different sites during the same contraction. This method can be used to detect the phase synchronization between uterine bursts as it respects the non stationarity of EHG signals and the non linearity of the propagation expected for uterine EHGs.

Since the uterus is supposed to work as a synchronized organ during labor and amplitude correlation has already been proven to be more important during labor than during pregnancy [7], we would have expected to obtain the same evolution for phase synchronization. The results presented here indicate the opposite. The same observations (increase in amplitude correlation and decrease in phase correlation) have also been observed on EEG signals during the transition from preictal (desynchronized system) to ictal (synchronized system) stage [10]. This phase desynchronization still needs confirmation and interpretation on a bigger database.

We also plan to use signals recorded during pregnancy and labor for the same woman. By studying the time-frequency phase synchronization longitudinally along the weeks of gestation, we expect to be able to define the parameters related to propagation of EHG signals during pregnancy and labor .If so; these methods could be used to predict preterm labor.

CONCLUSION

This paper presents the use of wavelet analysis in the study of phase synchronization between uterine electrical activities. We observed more phase synchronization during pregnancy than labor. These findings can possibly provide a method for differentiating between pregnancy and labor contractions. Although yet to be tested, they could also aid in distinguishing between contractions in labor at term and preterm. Ultimately, our goal is to detect preterm labor and so we find these results encouraging.

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Author: Mahmoud Hassan
Institute: School of Science and Engineering, Reykjavik University.
Street: Menntavegi 1
City: Reykjavik
Country: Iceland
Email: **hassan@ru.is**