Energy Distribution Analysis of Uterine Electromyography Signals

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Abstract

Today, many of the characteristics of the transabdominal uterine electromyogram (EMG) are well established. Some of these characteristics are currently used to monitor pregnancy and detect labor. However, further investigations are needed in order to improve true labor detection. We investigated in this study the way the energy distribution of the uterine EMG signal is modified during pregnancy and in labor. We analyzed recordings of uterine electrical activity in eleven women at different increasing pregnancy terms and at labor. We introduced a method for pregnancy monitoring based on the evolution of the energy distribution of the uterine EMG throughout gestation using wavelet packet transform (WPT). The results obtained from the analyzed data indicate that energy emerges significantly towards higher frequencies along gestation. Furthermore, we observed a noticeable difference in the energy distribution between two studied classes (pregnancy and labor). The results are supported by statistical analysis using t-test indicating good statistical significance with a confidence level of 95%. Our study provides convincing evidence that pregnancy can be monitored and labor can be detected by the means of uterine EMG using its energy distribution. Therefore, the analysis of uterine electrical activity can be very promising to identify preterm labor.

Keywords: Uterine electromyography (EMG), Energy distribution, Wavelet packet transform, Pregnancy monitoring

1. Introduction

Uterine electromyography (EMG) is a promising technique for monitoring uterine activity, based on recording the electrical activity of the uterus from the abdominal wall of pregnant women [1,2]. It is of primary interest because it is related to the electrophysiological process associated with the appearance of uterine contractions [3,4]. Over the years, uterine EMG has become the object of many studies [5-8]. It has been proved that it is of interest to offer a good insight into the process of pregnancy and labor [5,6]. Moreover, uterine EMG was heavily investigated in order to predict the risk of preterm labor and subsequent preterm birth [7,8].

Nowadays, classical statistical analysis in time and frequency domains has been widely explored. Temporal and spectral characteristics of the uterine EMG were defined in two physiological states: pregnancy and parturition. Some of these characteristics were used to monitor pregnancy and detect labor [9-11]. Of particular interest has been the energy of the uterine EMG. Marque et al. [12] observed spectral changes of the uterine EMG from pregnancy to parturition. They noticed high frequencies on the power spectral density as well as on the temporal shape for labor contractions. They concluded that pregnancy contractions are mainly characterized by low frequencies whereas labor contractions are related to the presence of high frequencies. Schlembach et al. [13] stated that there are measurable increases in the energy of the electrical activity and a rise in the high-frequency content of the action potentials. They reported that the increases are favored by the changes that occur in the electrical properties of the myometrium during labor to increase contractile force in the myometrial smooth muscle. Most recently, Diab et al. [14] used the wavelet transform (WT) to investigate the frequency content of the uterine EMG. Results showed that the frequency content changes from one woman to another, but also during pregnancy.

In this paper, an inspection of the modified energy distribution of the uterine EMG during pregnancy and throughout steps leading to labor is presented. Our method is based on the separation of the signal energy among different frequency bands using the wavelet packet transform (WPT). We aimed in our study to quantify the energy distribution in order to employ it in pregnancy monitoring and labor detection. Additionally, we sought to demonstrate that energy distribution represents a parameter that can significantly discriminate between the two classes of contractions (pregnancy/labor).
2. Materials and methods

2.1 Subjects

We studied 11 women: 5 recorded during pregnancy (33 – 39 week of gestation, WG) and 6 during labor (39 – 42 WG). Among the 5 women recorded during pregnancy, 2 women were recorded for different WG. After manual segmentation of the bursts of uterine electrical activity corresponding to contractions with the help of the tocodynamometer trace, we obtained 30 labor contractions and 30 pregnancy contractions. The measurements were made at the Landspitali University Hospital in Iceland using a protocol approved by the relevant ethical committee (VSN 02-0006-V2). They were performed by using a 16-electrode grid, arranged in a 4x4 matrix positioned on the women’s abdomens (Fig. 1). In this study, we considered vertical bipolar signals (Vbi) in order to increase the signal-to-noise ratio (SNR). Our signals thus form a rectangular 3 x 4 matrix. All the bursts presented a good SNR on all bipolar channels. Signals were sampled at 200 Hz. The recording device had an anti-aliasing filter with a cut-off frequency of 100 Hz. The simultaneous tocodynamometer paper trace was digitized to ease the segmentation of the bursts [15]. Throughout this study, all contractions have been normalized to have a standard deviation of 1 [16].

![Figure 1. Electrode configuration on the woman’s abdominal wall. The Vbi (i = 1 – 12) represent the derived bipolar signals.](image)

2.2 The wavelet packet transform

2.2.1 Background

The multiresolution analysis was first proposed by Mallat [17]. Wavelet packets were introduced by Coifman and Wickerhauser [18] as a generalized family of multiresolution orthogonal or biorthogonal basis. Unlike wavelet transform, which is realized only by a low-pass filter bank, WPT is implemented by a basic two-channel filter bank which can be iterated over either the low-pass or the high-pass branch. Therefore, the information in high frequencies as well as that in low frequencies can be analyzed with WPT. As a result, finer frequency bands can be obtained by WPT than by wavelet transform.

We start with \( h(n) \) and \( g(n) \), the two impulsive responses of low-pass and high-pass analysis filters, corresponding to the scaling function and the wavelet function, respectively. The sequence of functions is defined by:

\[
W_{2n}(x) = \sqrt{2} \sum_{k=-\infty}^{\infty} h(k) W_n(2x-k) \\
W_{2n+1}(x) = \sqrt{2} \sum_{k=-\infty}^{\infty} g(k) W_n(2x-k)
\]

where \( j \) is a scale parameter, \( k \) is a time localization parameter and \( n \) is an oscillation parameter. \( w_i(x) = \phi(x) \) is a scaling function which corresponds to a low-pass filter. The filtered signal is an approximation of the analyzed signal. The function \( w_i(x) = \psi(x) \) is the mother wavelet function that corresponds to a high-pass filter. The filtered signal is a detail of the analyzed signal. Consequently, the approximation and detail can be further decomposed by dyadic decomposition by using the dilated and translated scale functions and wavelet functions. In other words, the three indexed family of analyzing functions can be reached by:

\[
W_{j,n,k}(x) = 2^{-j/2} W_n(2^{-j} x - k)
\]

\( W_{j,n,k}(x) \) roughly analyzes the fluctuations of the signal around the position \( 2^j n \). The wavelet packets coefficients at each node \((j,n)\) are written as:

\[
C_{j,n}(k) = \left\{ f(t), 2^{-j/2} W_n(2^{-j} t - k) \right\}
\]

Figure 2 illustrates the wavelet packet decomposition tree with three levels.

Each node of the WP tree is indexed with the pair of integers \((j,n)\): \( j \) represents the level and \( n \) the number of nodes per level with \( n = 0, 1, \ldots, 2^j - 1 \). A vector of WP coefficients \( C_{j,n} \) corresponds to each node \((j,n)\), according to the basic step procedure. The length of a vector \( C_{j,n} \) is approximately \( N/2^j \). The frequency range corresponding to each node of the WP tree is approximately \( F/2^{j+1} \).

2.2.2 Wavelet and scale choices

The choice of the mother wavelet is a critical problem in signal processing theory. It must be well adapted to the characteristics of the studied signals [11,14,19]. In previous works related to the uterine EMG signal, the Symlet wavelet was used. It has been demonstrated that it gives the best results in terms of analyzing uterine EMG signals [20].

We assume in this work that the main energy of the uterine EMG is located in the \([0.34 – 3 \text{ Hz}]\) range [1,8,12,21]. Since the sampling frequency of the signals is 200 Hz, in order to reduce the number of decomposition levels, all the signals were first downsampled. Therefore, the bandwidth of each signal was reduced to 3.125 Hz. In this case, we are only interested to study the packets of level 3, where the signal is decomposed into 8 frequency bands and the bandwidth of each one is approximately 0.39 Hz.
3. Results

Figure 3 shows an example of the temporal shape of pregnancy contractions and the corresponding power spectrum densities (PSDs) for the same women (W1) at two different increasing pregnancy terms: (a) at 30 WG and (b) at 32 WG. Figure 3 evidences the rise in the high-frequency content on the PSDs as well as on the temporal shapes. We aimed in our study to quantify this rise by decomposing the total bandwidth of the uterine EMG into frequency bands and calculating the proportion of the energy in each frequency band at different increasing terms.

First, we studied the temporal variation of the energy distribution in the uterine EMG recordings along gestation. Figure 4 illustrates the evolution of the energy distribution in the frequency bands corresponding to the packet (3,0) representing the low-frequency content of the uterine EMG and the packets (3,1), (3,2) and (3,3) representing altogether the high-frequency content. These packets represent practically the total bandwidth of the uterine EMG signals. These packets allowed us to monitor the variation of the energy distribution in the frequency bands [0 – 0.39 Hz], [0.39 – 0.78 Hz], [0.78 – 1.17 Hz] and [1.17 – 1.56 Hz], respectively. The remaining packets contained basically less than 1% of the total energy, hence they were excluded from our study. Data used in this part were recorded on two women (W1 and W2) at two and three increasing pregnancy terms, respectively. First, we computed the percentage of energy corresponding to each node of the packet tree over the matrix of signals related to each contraction. Then we determined their average over all the contractions during the recording sessions: 2 contractions at 30 WG (G1) and 2 contractions at 32 WG (G2) for the first woman, W1, and 4 contractions at 33 WG (G’1), 2 contractions at 35 WG (G’2) and 3 contractions at 37 WG (G’3) for the second woman, W2. The mean values were determined for each woman at each term and plotted against the woman’s weeks of gestation interval (Fig. 4). The results show that there were energy distribution changes throughout gestation: there was a noticeable decrease in the energy proportion in the first packet representing the lowest frequency band, whereas there was an increase of the energy proportions in each of the remaining packets representing the rest of the bandwidth of the studied signal. Therefore, we grouped all these packets into one representing the frequency band where it was shown that the energy proportion increases.
4. Discussion

Several techniques have been adopted to monitor and/or to diagnose labor [22]. However, from our study as well as those of others [1,2,5-10], it is clear that changes in uterine electrical activity are associated with the progression of pregnancy and the onset of labor. Changes of the characteristics of the uterine activity along the course of gestation are induced by the changes that occur in the electrical properties of the uterus during the gestational period and labor. It has been demonstrated that the increase in electrical activity during labor is secondary to an increase in the ability of the muscle cells to generate action potentials and to an increase in the propagation of action potentials [23].

In the first part of our work, we observed that the uterine EMG energy, which spreads across the bandwidth of the signal, undergoes spectral changes throughout pregnancy as well as from pregnancy to labor. Our study indicates that the energy distribution follows a very particular path during gestation. We showed that, as the time of delivery approaches, the energy of the signal emerges from low frequencies into higher frequencies. This is coherent with the results presented in
different studies either on women [12,13] and on animals [10]. Our results revealed that the proportion of energy in two frequency bands (low and high) of the signals changes gradually during pregnancy and exhibits a longitudinal evolution throughout gestation.

Additionally, noticeable differences in the energy distribution of the electrical signals that originate from pregnancy and laboring patients have been shown to be able to successfully distinguish the two types of recordings (pregnancy or labor) from one another. The results obtained indicate that energy distribution is a parameter that can distinguish pregnancy and labor contractions with more than 95% confidence (using t-test). This information may provide important evidence for the onset of labor, and it may help identify premature labor.

5. Conclusions

In the described work, we studied the energy distribution of the uterine EMG throughout gestation. The study demonstrated that the energy distribution, similarly with many other extracted features from the uterine EMG signals, gradually changes during pregnancy. We noticed that, throughout pregnancy, energy emerges towards higher frequencies. Thus, we concluded that labor is not a direct transition from an inactive to an active state of the uterus. Furthermore, these results may help improve our understanding of the physiological basis of uterine electrical activity and the progression of pregnancy as well as how labor is initiated. This may help improve the capacity of the uterine EMG signal to identify true labor in order to help identify patients who are likely to deliver prematurely.

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References
