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Early diagnosis of threatened premature labor by electrohysterographic recordings – The use of digital signal processing

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ABSTRACT

Prevention and early diagnosis of imminent preterm labor are considered to be the most important perinatal challenge nowadays. Significant progress has been observed on postnatal care of premature infants, but without reducing the prevalence of preterm delivery.

Our study was focused on comparison of three methods of spectral analysis of electrohysterographic (EHG) signals: fast Fourier transform (FFT), wavelet transform (WT) and autoregressive modeling (AR). Complexity of the electrohysterographic signals was analyzed by using: the approximate entropy (ApEn), Lempel–Ziv complexity measure (L–Z). Additionally, the work evaluated the applicability of EHG in diagnosing imminent premature labor.

EHG signals were recorded among 60 patients with threatened preterm labor symptoms between the 24th and 34th week of pregnancy. Patients included to the study had a shortened cervix (less than 20 mm) without regular uterine contractions recorded on regular cardiotocography (CTG). The women were divided into two groups: those delivering within 7 days – group A ($n = 15$) and women delivering after 7 days – group B ($n = 45$).

The study confirmed differences in bioelectrical activity of uterus between patients delivering prematurely within 7 days and after from the EHG registration for all analyzed methods.

1. Introduction

Preterm labor is defined as premature birth between the 24th and the 37th week of pregnancy, before the developing organs are mature enough to allow normal postnatal survival. Premature infants are at greater risk for short and long term complications, including disabilities and impediments in growth and mental development. Significant progress has been made in the care of premature infants, but not in

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reducing the prevalence of preterm delivery [1]. Preterm birth is among the top causes of death in infants worldwide. Prevention and early diagnosis of imminent preterm labor are considered to be the most important perinatal challenge nowadays. In 2005, preterm birth cost the United States at least $26.2 billion, or $51,000 for every infant born prematurely. Symptoms of imminent spontaneous preterm birth, are signs of premature delivery. At least four uterine contractions observed in 1 h of patients monitoring or observed cervical length less than 25 mm are the most important signs of preterm delivery. In contrast to false labor, true labor with regular uterine contractility, is accompanied by cervical dilatation and effacement. A helpful clinical diagnostic marker should allow to predict a high risk for preterm labor during the early and middle part of the third trimester, when the mortality of preterm infants is the highest. Many patients experience false labor, do not lead to cervical shortening and effacement, and are falsely labeled to be in preterm labor.

The study on the risk factors and clinical markers of preterm labor are very difficult, because of distinguish between true and false labor. Most of research methodologies for studying preterm uterine contractility have focused on selected biochemical and molecular markers detected in serum or urine of pregnant patients [2–7]. Biophysical detection of preterm uterine contractility is mainly focus on cardiotocography and ultrasound cervical length measurement, but these methods presented many limitations [8,9]. There are still lots of efforts leading to find an ideal diagnostic procedure allowing to predict preterm uterine contractility leading to cervical shortening and preterm labor. Electrohysterography (uterine electromyography) method based on recording of uterine electrical activity, seems to be a promising method allowing to assess uterine activity during pregnancy [10,11]. Changes in electrical potentials are associated with the mechanical activity i.e. contractions of uterine muscles [12,13]. Here are controversies if uterine electrohysterography may identify the patients with high risk of preterm labor [14–16]. There is a need to check various methods of mathematical interpretation of recorded time series.

The aim of the study was: (i) to compare the results from three methods of power spectral analysis i.e. fast Fourier transform (FFT), wavelet transform (WT), and autoregressive modeling (AR), (ii) to assess complexity of the electrohysterographic signals by using: the approximate entropy (ApEn), and Lempel–Ziv complexity measure (L–Z), as well as (iii), to evaluate the usefulness of EHG in the prediction preterm delivery.

2. Material

Electrohysterographic signals were recorded in 60 patients with threatened preterm labor symptoms between the 24th and the 34th week of pregnancy. The recording was carried out at Department of Perinatology of the University Hospital of Białystok, Poland. Patients included to the study had a shortened cervix (<25 mm) without regular uterine contractions on cardiotocography (CTG). The women were divided into two groups: those delivering within 7 days – group A ($n = 15$) and women delivering after 7 days – group B ($n = 45$).

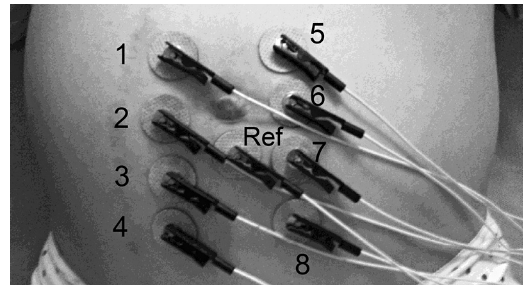

Fig. 1 – Electrode locations for the present study, Ref – reference electrode.

In the research, a custom created system was used (Neuron-Spectrum 5, Neurosoft Ltd, Russia). The system allowed 8 channel signal registration in 8 different points of abdominal wall over the pregnant uterus (Fig. 1, Fig. 2). The sampling frequency was 200 Hz. The mean and linear trend were removed. The signals were multiplied by hamming window and filtered with a low-pass and high-pass filters to yield a band-pass of 0.24–4.00 Hz was used to eliminate undesired component. Similar frequency ranges have been used by other researchers (0. 2–4.0 Hz [17] or 0.1–3.5 [18]). The signals recording time ranged from 30 min to 45 min. For spectral analysis, the signals were decimated to a sampling rate of 20 Hz. Next, fragments of signals were selected in such a way that the length of each analyzed signal was 8192 samples. The analysis concerned the recorded signals from electrode E4 for spectral and complexity analyses. In the case of ApEn and L–Z the measures signals were not decimated. To predict preterm birth it is sufficient to study one recorded signal. This is important in telemetry.

3. Methods

3.1. Spectral analysis

Fourier transform (FT), wavelet transform (WT) and autoregressive modeling (AR) are the most popular methods of spectral data analysis [19,20]. The Fourier transform of a signal x(i) is defined as [21]:

$$X(f) = \frac{1}{N}\sum_{k=0}^{N-1} x(n)e^{\frac{-i2\pi fk}{N}} \quad (1)$$

where f is the frequency.

FT is a description of how the signal is constructed from sinusoids of different frequencies. Power spectrum or power spectral density function:

$$P(f) = |X(f)|^2 \quad (2)$$

gives a measure of the contribution to the signal made by each of its sine wave component.

Contrary to the Fourier decomposition, which is global and provides the information integrated over the whole signal, the continuous and discrete wavelet transforms allow extracting local and global variations of the recorded contractions. Scalogram show the distribution of energy in the