Antepartum Fetal Monitoring and Spectral Analysis of Preterm Birth Risk

Alexandru Păsăricăra¹, Dragoș Nemescu², Dragoș Arotăriței³, Cristian Rotariu⁴

1. Department of Telecommunications, “Gh. Asachi” Technical University Iasi, Romania, Faculty of Electronics, Telecommunications and Information Technology
2. Department of Obstetrics and Gynecology. “Grigore T. Popa” University of Medicine and Pharmacy Iasi, Romania, Faculty of Medicine
3. Department of Biomedical Sciences, “Grigore T. Popa” University of Medicine and Pharmacy Iasi, Romania, Faculty of Medical Bioengineering

e-mail address: cristian.rotariu@umfiasi.ro

Abstract. The monitoring and analysis of antepartum fetal and maternal recordings is a research area of notable interest due to the relatively high value of preterm birth. The interest stems from the improvement of devices used for monitoring. The current paper presents the spectral analysis of antepartum heart rate recordings conducted during a study in Romania at the Cuza Voda Obstetrics and Gynecology Clinical Hospital from Iasi between 2010 and 2014. The study focuses on normal and preterm birth risk subjects in order to determine differences between these two types or recordings in terms of spectral analysis.

1. Introduction
Preterm birth risk is an issue of interest for health care professionals given the most recent European statistics presented in the European Perinatal Health Report 2010 [1], which show rates is between 5 and 10% for all European countries, and 8% for Romania. A method used due to the advancement of technology is fetal and maternal monitoring that can be done both invasively and non-invasively. Of course, non-invasively techniques are desired due to the low risk involved for both the mother and the child. These devices are attached to the patient’s abdomen and acquire data from the mother and the fetus. The data acquired can vary, but the main signals are the fetal and maternal heart rate and the maternal uterine contractions [2]. Long term monitoring of these parameters during the later stages of pregnancy, the third trimester, can be used as a screening technique in order to reduce preterm birth risk. The monitoring technique is always accompanied by the expertise of health care professionals [3].

The results presented in this paper represent the spectral analysis of antepartum recordings of fetal and maternal heart rate (FHR and MHR) during the third trimester of pregnancy. The analysis focuses on both normal and preterm birth risk recordings in order to determine the differences between the two types of recordings. The spectral analysis method is well established as a reliable method for identifying relevant information from HR recordings [4]. The method can be used for long term recordings, such as those acquired during fetal and maternal monitoring. The purpose is to show the efficiency of this type of clinical practice as a complimentary procedure to standard testing such as echography during key stages of pregnancy and close observation from health care specialists.
The fetal and maternal monitoring and analysis of recordings has been the subject of other articles, either on the identification of pathological recordings of fetal acidosis during labour, such as Costa et al. [5], Siira [6], Spilka et al. [7], Georgieva et al. [8], Pasarica et al. 2015 [9] and Ungureanu et al. 2013 [10], or identification of preterm birth risk, such as Khandoker et al. 2016 [11], where the partial directed coherence (PDC) method is used to compare different stages of the pregnancy, or preterm birth risk in Pasarica et al. 2016 [12].

2. Materials and methods

2.1. Database
The analysis presented was performed using a database of long term fetal and maternal HR recordings. These were acquired during the period 2010-2014 at the “Cuza Vodă” Obstetrics and Gynecology Clinical Hospital from Iasi, Romania. The device used to acquire data was the Monica AN24 portable non-invasive fetal heart rate monitor [13] produced by Monica Healthcare, Nottingham UK. The device got FDA (US Food and Drug Administration) approval in February 2011 and studies presenting the performance of this device show comparable waveforms to those obtained by using Doppler echography [14]. The database created consists of 112 fetal and maternal HR (FHR and MHR measured in beats per minute - bpm) recordings between the 25th and 28th week of pregnancy. The sampling frequency for the data acquired during 24-hour recording period is 4 Hz.

In order to ensure patient safety, the entire data acquisition process was explained to the patients in both procedures and possible risks. The risks of this monitoring procedure are low due to the non-invasive nature of the device and the low electrical security issues, given that the device is powered by a battery. After all the necessary information was presented, each patient had given written consent to take part in this study and for the data acquired to be used in further research applications. We ensured the privacy of the patients by anonymising the recordings.

The database recordings were divided into two groups based on clinical parameters determined by health care professionals. The main clinical parameter taken into consideration is represented by the cervical length measured during the beginning of the third trimester (weeks 25 to 28). Clinical observation has shown that patients that present a cervical length less than 25 mm are indicative of high risk situations (preterm birth risk) whereas patient with cervical length over 25 mm are indicative of low risk situations (normal recordings) [19]. Based on these parameters the database was divided into two groups: the control group which consists of 64 normal recordings and the study group with 48 pathological or suspicious recordings of high preterm birth risk.

2.2. Method
In order to improve the signal quality a series of pre-processing methods were used for both FHR and MHR. The first step is applying a smoothing filter based on a Hanning window of 30 samples with an overlap of 10 samples which allows us to remove sharp changes in the signal values [15]. The window overlap has the purpose to prevent information loss towards the extremities of the interval where values tend to zero. We chose a Hanning window because it reduces the generation of side lobes.

The second step consists of applying a cubic spline interpolation in order to remove artifacts caused by poor contact between the patient’s skin and the electrodes. These artifacts result in the replacement of FHR and MHR values with the value 0 which can heavily modify the results.

The decomposition of the fetal and maternal heart rate into frequency components is a useful tool in bio-signal processing field. The heart rate variability (HRV) method is used to determine frequency and time domain parameters. The frequency domain analysis consists of the computation of the Fast Fourier Transform for three non-overlapping energy bands specific to FHR or MHR. For FHR the frequency bands are low frequency LF (0.03-0.07Hz), mid-frequency MF (0.07-0.13Hz), and high frequency HF (0.13-1Hz) [16]. For MHR the frequency bands analysed are low frequency LF between 0.03 and 0.16 Hz, mid frequency between 0.16-0.6 Hz and high frequency 0.6 to 3 Hz. We used the
normalized values of the mid and high frequency bands for both FHR and MHR and the mid and high frequency ratio as the main parameters because these are best suited to highlight the influence of the physiological activity of the fetus and the mother (nMF, nHF and MF/HF for MHR and FHR) [17]. The time domain analysis is used to determine the indicators SDNN, SDANN, pNN50, RMSSD, and meanHR, with formulas described in the literature [18].

3. Experimental results
The low and high frequency bands (LF and HF) were selected to perform the signal analysis because these provide the most useful information with respect to fetal and maternal physiological activity. The values obtained for each recording are normalized accordingly with equations (1) and (2) and used to compute the medium frequency to high frequency ratio (the sympathetic influence over the FHR signal) using the by using the equation (3) as they are described in [9].

\[
\text{nMF} = \frac{\text{MF}}{\text{LF} + \text{MF} + \text{HF}} \times 100 \\
\text{nHF} = \frac{\text{HF}}{\text{LF} + \text{MF} + \text{HF}} \times 100 \\
\text{LFHF} = \frac{\text{LF}}{\text{HF}}
\]  

(1) (2) (3)

Figure 1 presents the results obtained for parameter LFHF. The figure shows that the parameter values obtained for the MHR data are normal for both the control and study group, whereas the mean parameters values obtained for the FHR data are different between the two groups. These results are confirmed by the mean values presented in Table 1: LFHF presents mean value 117.5 for the control group and 390.29 for the study group, RMSSD has the mean value 7.982 for the control group and 12.7 for the study group, SDNN presents 41.26 for the control group and 53.46 for the study group, SDANN has the mean value 18.86 for the control group and 24.12 for the study group. Overall, we can observe that the mean values for the study group for all the parameters previously mentioned are higher than the mean values obtained for the control group. This can be explained by the fact that preterm birth risk manifest in an increase in contractions in the third trimester which leads to an increase of the FHR. This can lead to pathological situations such as the early onset of labour, preeclampsia or the development of fetal acidosis due to the lack of oxygen that is delivered through the umbilical cord to the fetus.

Figure 2 presents the data dispersion for the parameters that present significant difference between the control and study group for the FHR data. The highest degree of separation between groups is obtained for the frequency domain parameter LFHF.

![Figure 1. Mean values for the frequency domain indicator LFHF](image1)

![Figure 2. Data dispersion of the LFHF indicator values for FHR (control and study group).](image2)
Table 1. HRV parameters mean values for FHR and MHR (control group).

|                | FHR (control group) | FHR (study group) | MHR (control group) | MHR (study group) |
|----------------|---------------------|-------------------|---------------------|-------------------|
| mean nLF       | 0.989               | 0.004             | 0.887               | 0.004             |
| SD nLF         | 0.004               | 0.004             | 0.004               | 0.004             |
| mean nHF       | 0.01                | 0.01              | 0.112               | 0.112             |
| SD nHF         | 0.004               | 0.004             | 0.004               | 0.004             |
| mean LFHF      | 117.5               | 56.57             | 390.29              | 24.98             |
| SD LFHF        | 24.98               | 24.98             | 24.98               | 24.98             |
| mean pNN50     | 0.371               | 0.328             | 0.4                 | 0.334             |
| SD pNN50       | 0.4                 | 0.023             | 0.003               | 0.025             |
| mean RMSSD     | 7.982               | 3.458             | 12.7                | 5.227             |
| SD RMSSD       | 3.458               | 3.458             | 3.458               | 3.458             |
| mean SDNN      | 41.26               | 19.71             | 53.46               | 26.02             |
| SD SDNN        | 19.71               | 19.71             | 19.71               | 19.71             |
| mean SDANN     | 18.86               | 8.812             | 24.12               | 10.668            |
| SD SDANN       | 8.812               | 8.812             | 8.812               | 8.812             |
| mean HR        | 120.65              | 27.5              | 119.63              | 30.89             |
| SD mean HR     | 27.5                | 27.5              | 27.5                | 27.5              |

We also computed an unpaired Student “t” test in order to determine the validity of the results, presented in Table 2. The null hypothesis tested between the control and the study group shows similarly to the data dispersion and significant difference for the FHR indicators LFHF, RMSSD, SDNN and SDANN. The p value obtained for all these indicators is below 0.05 (5%).

Table 2. Results of the Student t test performed between the control and study groups

| FHR indicator | H     | p     | Standard deviation | Confidence interval (95%) |
|---------------|-------|-------|--------------------|--------------------------|
| nLF           | 0     | 0.711 | 0.0046             | [-0.0021, 0.0014]         |
| nHF           | 0     | 0.711 | 0.0046             | [-0.0014, 0.0021]         |
| LFHF          | 1     | 0.0017| 140.66             | [-326.01, -219.55]        |
| pNN50         | 0     | 0.633 | 0.331              | [-0.155, 0.095]           |
| RMSSD         | 1     | 0.0082| 4.304              | [-6.352, -3.094]          |
| SDNN          | 1     | 0.0056| 22.625             | [-20.761, -3.638]         |
| SDANN         | 1     | 0.0051| 9.649              | [-8.916, -1.613]          |
| mean HR       | 0     | 0.853 | 29.002             | [-9.951, 11.998]          |

4. Conclusions
HRV analysis can be used to establish significant differences between normal and pathological FHR recordings, due to the frequency domain parameter LFHF and the time domain parameters RMSSD, SDNN and SDANN.

The analysis performed did not offer significant information in relation to the MHR data, results indicated by the normal mean values obtained for both the control and study group.

The data dispersion presented a high degree of separation for the LFHF parameter obtained for the analysis of FHR data, due to the increase of FHR values in pathological recordings as a results of more frequent uterine contractions.

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