THE CARDIOTOCOGRAPHY: FREQUENCY ANALYSIS OF THE FETAL HEART RATE VARIABILITY

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Abstract: Nowadays the cardiotocography (CTG) represents the most used clinical methodology to estimate the foetal health in a non-invasive way. The analysis of the CTG recordings is based mainly on a their visual inspection, so the efficiency of this methodology is related to the expertise and training of the obstetrics, but obviously it lacks of objectivity and reproducibility. The aim of this study was trying to improve the interpretation of CTG recordings, making it as objective and reproducible as possible. In particular, in this study, we intended to characterize the foetal reactivity by the frequency analysis of the FHRV, and eventually to arrive to one clearer distinction between CTG recordings correspondent to the healthy foetuses and CTG recordings correspondent to not reactive foetuses. In order to achieve such an aim we analysed separately the healthy foetuses data and the not reactive foetuses data, and then we did a comparison between them.

Introduction

Nowadays the cardiotocography (CTG) represents the most used clinical methodology to estimate the foetal health in a non-invasive way. The introduction of this diagnostic technique, like a routine control during the pregnancy, has concurred to remarkable steps ahead in the reduction of perinatal mortality and morbility. However, being the analysis of the CTG recordings mainly based on a visual inspection, such this methodology is affected with some level of subjectiveness and it strongly depends on the personal experience. The aim of this study was trying to improve the interpretation of CTG recordings, making it as objective and reproducible as possible. In order to achieve such an aim we inquired into new analysis methodologies, such as the frequency analysis of FHRV (Fetal Heart Rate Variability). FHRV is probably the most important feature of the FHR signals.

The FHRV around the baseline is due to the cardiac rate control mechanisms by the two branches (sympathetic branch and parasympathetic or vagal branch) of the Autonomous Nervous System (ANS). In fact, the sympathetic branch accelerates heart rate, while the parasympathetic branch has a decelerator effect; the regulation is performed by feed-back control mechanisms, in which baroceptors play a main role.

Statistically, variability is commonly expressed by the width of the distribution of either R-R intervals or heart rates. Short-term and long-term variability are distinguished. Short-term variability refers to the variation in difference between successive R–R intervals, while long-term variability refers to the fluctuation in the FHR over seconds or minutes. Short-term variability is difficult to interpret reliably with the naked eye. Thus, in clinical practice, baseline variability refers often to long-term variability (Rooth et al, 1987)[1].

Variability is considered to be normal if its amplitude of around the baseline is between 5 and 25 beats (Rooth et al, 1987), although other authors consider 5-15 bpm to be the normal range (Schifrin, 1989; Cabaniss, 1993)[1]. A flat baseline heart rate (variability 0-2 bpm) is one of the most severe FHR patterns. The literature, in fact, highlights that generally an insufficient variability is associated to the situations of foetal distress, for example hypoxia, instead a condition of foetal well-being is associated to a "variable rhythm"[2].

FHRV is usually presented as a function of time, but a deeper understanding of its behaviour is offered by studying its representation in the frequency domain. The frequency analysis can be useful since the different components of the FHRV power spectrum are connected to the various control mechanisms of the cardiac rhythm by the ANS [3].

In this study, through the frequency analysis of the FHRV, we intended to characterize the foetal reactivity, where, as specified in literature, a foetus is defined as "reactive" if its FHR tracing shows two or more accelerations in a twenty minute period. The reactivity indicates the ability to the foetus to react to inner and/or external stimuli and in particular to stress situations [6]. Also this classification ("reactive or not") is often based on a visual inspection of the CTG recordings.

The aim of this analysis was to characterize in a clearer and objective way the foetal reactivity, analysing FHRV in frequency domain and eventually obtaining a clearer distinction between CTG recordings correspondent to healthy foetuses and CTG recordings correspondent to not reactive foetuses. In order to

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achieve such an aim we analysed separately the healthy foetuses data and the not reactive foetuses data, and then we did a comparison between them.

Materials and Methods

The data employed for this research were extracted from a database of about 1500 patients supplied by the "Policlinico II" University Federico II, Hospital of Naples.

CTG traces were recorded by means of CTG HP M11351A.

The FHR is a time-discrete signal (a sample is available only when a new beat occurs), while the UC is a time-continuous signal. To realise a time-alignment of these two signals, the cardiotocograph samples both signals at a fixed rate (2 Hz in our case), using a zero-order interpolation for the FHR values.

From that database, we selected about 700 ante-partum, without uterine contractions, tracings. The uterine contractions, causing a remarkable increase of the intrauterine pressure, represent a strong stimulus for the foetus which can induce specific modifications in the foetal cardiac rhythm and consequently in the FHRV power spectrum. This situation, therefore, demands a specific analysis that was not included among the context of this study [4].

Then, with the help of a clinical team, we divided the selected tracings in two groups. The first group consisted of about 500 CTG recordings relative to foetuses that showed a good variability of the FHR (tracings in which attended at least two acceleration in twenty minutes of FHR registration). This first group of tracings was considered, in according to literature, relative to reactive foetuses. Figure 1 shows an example of CTG recording relative to a reactive foetus.

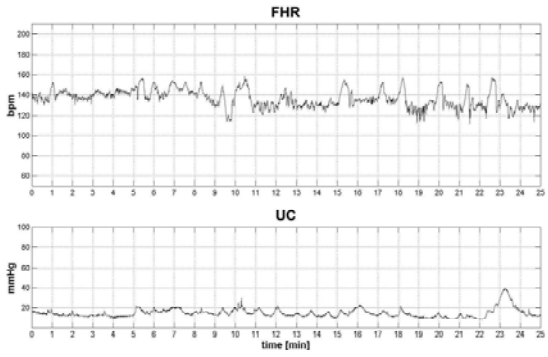

Figure 1: Example of tracing where it is evident that the FHR signal shows a good variability and numerous accelerations in a twenty minute period

A second group of tracings consisted of about 150 CTG recordings relative to foetuses that showed a reduced variability of the FHR. This second group of tracings was considered relative to not reactive foetuses. Figure 2 shows a CTG recording relative to a not reactive foetus.

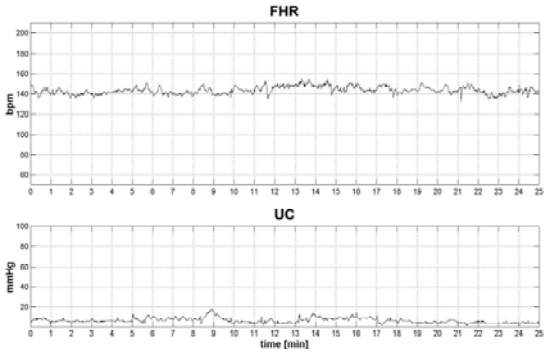

Figure 2: Example of tracing where it is evident that the FHR signal shows a reduced variability and there aren't accelerations in a twenty minute period

The CTG recordings classification often is not simple; in fact there are case in which the FHR signal shows a good variability but don't attend two acceleration in a twenty minute period and there are case in which FHR registration shows a reduced variability but attend two acceleration in a twenty minute period (see fig. 3).

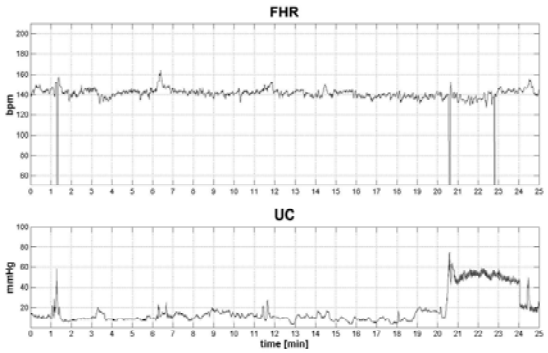

Figure 3**:** Example of difficult classification CTG recording relate to a reactive foetus that shows a reduced variability

Before realising the analysis we did a data pre-processing to eliminate outliers, artefacts and unreliable signal tracts.

Then, in order to extract the FHRV, we eliminated the floatingline and the dc components from the FHR by not linear filters.

To avoid spectrum alterations related to specific stimuli, we focused the analysis only on FHRV chunk of three minutes length without evident rhythm modifications (accelerations, decelerations) and in absence of uterine contraction.

We estimated time-frequency matrices of the CTG recordings. The time-frequency analysis was realised by means of Short Time Fourier Transform (STFT) (for the non-stationariety of the FHRV signal). The window length was chosen of 64 samples (which corresponds to 32 s) according to literature information. Then, we determined the average of the

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Power Spectral Density (PSD) relative to the first CTG recordings group and, separately, the average of the PSD relative to the second CTG recordings group (see fig. 4 and 5).

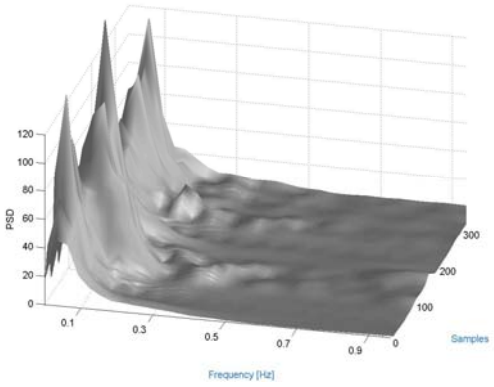

Figure 4: 3D representation of the average of the Power Spectral Density relative to the reactive foetuses (500 CTG recordings)

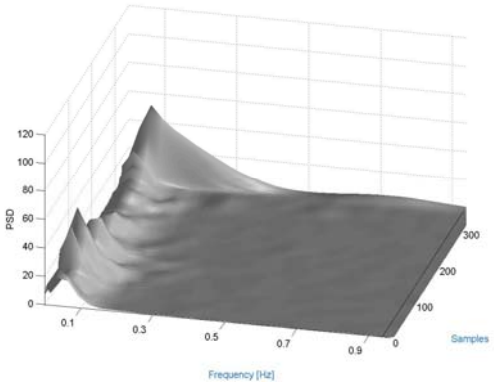

Figure 5: 3D representation of the average of the Power Spectral Density relative to the not reactive foetuses (150 CTG recordings)

With a similarity of what happens in adult human subjects, foetuses manifest variability in correspondence of particular bands in the spectrum which are sensitive to sympatho-vagal balance, which controls many cardiovascular functions and respiration in different physiological conditions. A further insight shows that there's a Very Low Frequency (VLF) lobe, 1/f shaped, below 0.01 Hz, related to slow controls (thermal and humoral), a Low Frequency (LF) lobe around 0.1 Hz reflecting sympathetic regulation, and High Frequency (HF) one above 0.3 Hz, not always present, regarding vagal activity [5].

So, we eximated the maximum power of the FHRV, the frequency of the maximum value of the PSD, the medium power, and the standard deviation in three intervals of frequency (0-0.2 Hz, 0.2-0.4 Hz, 0.4-0.8 Hz). We focused the attention into the interval 0-0.2 Hz, in which about 75% of the total spectral power is located. Finally, we did a statistical comparison (*t*-test) of the average of the PSD relative to the reactive foetuses with that one relating to the not reactive foetuses.

Results

The time-frequency analysis evidenced that PSD relative to the reactive foetuses shows values of the maximum and mean power higher if compared with those shown from PSD relative to the not reactive foetuses but there aren't big difference between the frequency of the maximum value of the PSD (see table 1, 2 and 3).

Table 1: Results obtained in frequency interval 0-0.2 Hz

PSD	Maximum power [bpm^2/Hz]	Frequency of the maximum value [Hz]	Medium power [bpm^2]	Standard deviation
reactive group	148.71	0.06	8.17	2.36
not reactive group	51.27	0.09	1.64	1.15

Table 2: Results obtained in frequency interval 0.2-0.4 Hz

PSD	Maximum power [bpm^2/Hz]	Frequency of the maximum value [Hz]	Medium power [bpm^2]	Standard deviation
reactive group	33.83	0.22	1.37	0.66
not reactive group	26.28	0.22	0.18	0.47

Table 3: Results obtained in frequency interval 0.4-0.8 Hz.

PSD	Maximum power [bpm^2/Hz]	Frequency of the maximum value [Hz]	Medium power [bpm^2]	Standard deviation
reactive group	11.37	0.41	0.72	0.35
not reactive group	4.37	0.41	0.10	0.12

Each of the two populations have many different power values (see fig. 6 and 7), so the two distributions overlap and it is not possible to separate statistically reactive foetuses from not reactive foetuses (in fact the *t*-test resulted negative).

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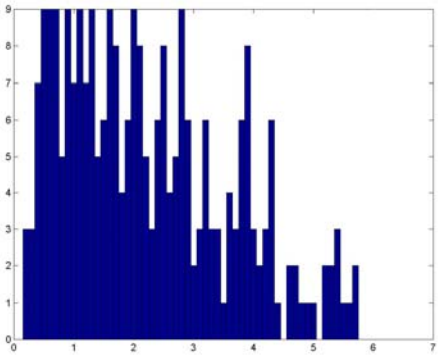

Figure 6: Histogram of the average of the power relative to the reactive foetuses.

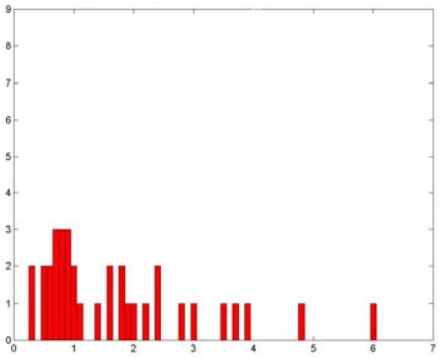

Figure 7: Histogram of the average of the power relative to the not reactive foetuses.

Discussion

Cardiotocography is the most diffused prenatal diagnostic technique in clinical practice for foetal assessment.

The major drawbacks of cardiotocography is related to the difficulties in reading and interpreting the FHR tracings, which is partly due to the many factors that may affect the FHR and its variability and to the lack of consensus among obstetricians on how to read and interpret FHR tracings [1].

The obstetrics, in order to establish foetal health state, recognise specific clinical signs as the foetal reactivity. Usually, in practical clinical medicine, the foetal reactivity is valued in time domain through a visual inspection of the FHR signals (a foetus is considered as “reactive” if his FHR tracing shows two or more accelerations in a twenty minutes period). So the interpretation of the CTG traces is based on the obstetrician expertise. Therefore, a more objective and quantitative interpretation would increase its reability [6].

This study intended to characterize the foetal reactivity by the frequency analysis of the FHRV.

This last one is a very important parameter for the evaluation of the foetal well-being. In fact, loss of the variability in the FHR is generally felt to be negative findings regarding foetal wellbeing. On the other hand, presence of reasonable FHR variability generally is equated with a functional responsive foetal Autonomic Nervous System [2].

The results obtained seem to indicate that the frequency analysis of the FHRV is not useful to characterize in a clearer and objective way the foetal reactivity.

Conclusions

In this study, we tried to characterize the foetal well-being through the frequency analysis of the FHRV.

To this end, we estimated the time-frequency matrices comparison (*t*-test) of the average of the PSD relative to the reactive foetuses with that one relating to the not reactive foetuses. This comparison evidenced that the two PSD shows different values of the maximum and mean power, but the two distribution overlap and it is not possible to separate statistically reactive foetuses from not reactive foetuses.

This result does not agree with the results obtained in the past with an similar analysis carried out on a different database. The main difference between the two database is the sampling frequency. Therefore, we plan, in a future activity, to go into this analysis, pointing out the eventual influence of the sampling frequency on the results.

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