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Evaluation of floatingline and foetal heart rate variability

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ABSTRACT

Foetal heart rate (FHR) variability is known to be a very important feature in the diagnosis of foetal well-being. Despite its clinical importance and the widespread use of foetal monitoring, a standard definition of FHR variability (FHRV) and an agreement concerning the methodologies to be employed in its evaluation are still lacking. Often, FHRV is computed in tracts of FHR signals in which both accelerations and decelerations are absent, thus making it very difficult to assess it for signals with several and closely spaced events of this kind.

In this work, we propose an automated method for estimating the FHRV signal, defining it as the difference between the FHR signal and the floatingline, where the latter is the imaginary line that follows accelerations and decelerations, taking into account the frequency characteristics of these events.

We tested the software developed for this purpose on both simulated and real FHR signals (sets of 50 signals). In the case of simulated signals, the average value of the mean square error vector between the simulated floatingline and that estimated was only 0.04 bpm^2. In the case of real signals, however, in absence of a reference gold standard, the estimated floatinglines were visually assessed by a team of five expert obstetricians who judged them matching to the definition in 96% of cases.

As regards the evaluation of FHRV, using the simulated FHR signals, we compared the estimated values with the reference values of short term variability (STV) and sympathovagal balance (SVB), two very significant parameters employed in computerised foetal monitoring, and obtained an error lower than 1.5% for the STV index, and an underestimation of the SVB index with an error of about 4.5%.

Finally, we compared the proposed method for the estimation of the floatingline with more traditional filters (moving average and FIR with Hamming window) which showed, on average, a worse performance (quantified by mean square errors up to five times higher).

1. Introduction

Foetal surveillance is a very important area in the context of health care. It has two main objectives: to exclude foetal abnormality, the predominant aim of monitoring in the first half of pregnancy, and to evaluate the health of the presumably normal foetus. With reference to the latter aim, auscultation and observation of foetal heart rate (FHR), by means of various techniques, has always been of crucial importance. Nevertheless, since the foetus is in the womb, several measuring problems arise. Cardiotocography (CTG), which simultaneously records FHR and uterine activity, is the routine test to ascertain foetal well-being at the end of pregnancy. Electrocardiography (ECG) and magnetocardiography are possible alternative techniques, but the former is limited by the problematic access to the foetus and by the complex procedures for signal processing needed to obtain foetal ECG through abdominal recordings, while the latter presents very similar problems and is rarely found in clinical environments due to its cumbersome nature and cost [1].

In order to diagnose foetal well-being, gynaecologists evaluate several characteristics of the FHR signal, and FHR variability (FHRV) is one of the most important of them, due to its relationship to the autonomic and central nervous systems, as demonstrated by pharmacological experiments, both in foetal sheep and in adult humans [2–4], and since it is related to the instantaneous foetal oxygenation [1].

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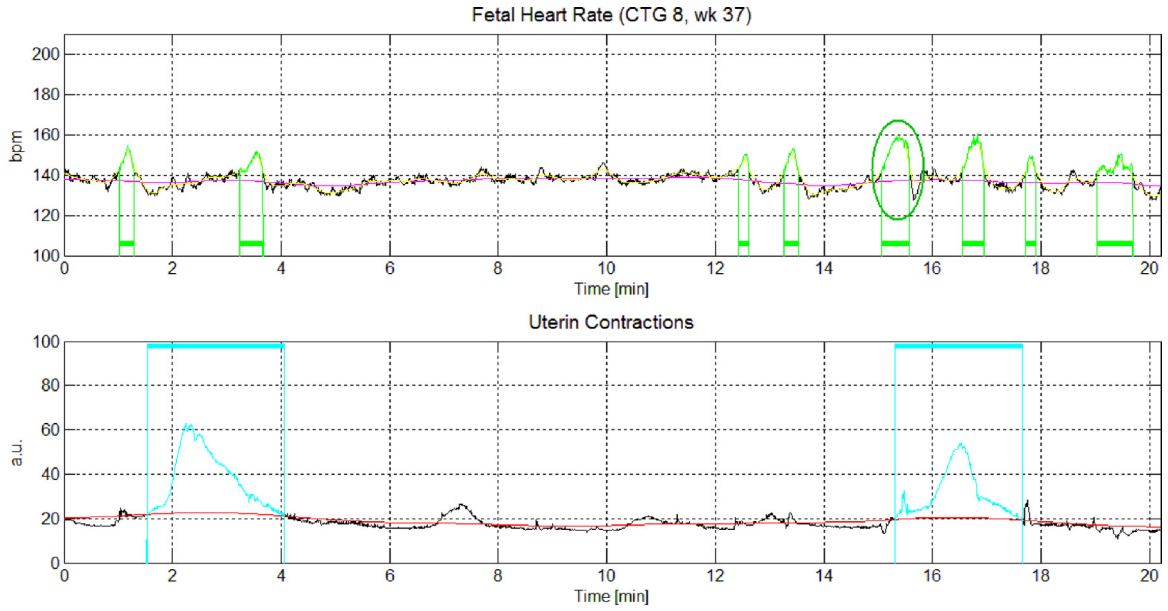

Fig. 1. CTG # 8 (internal numbering of our database). On the top FHR, on the bottom UC signal. Accelerations (green line) and contractions (cyan line) as selected by the procedure developed by the authors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The important role of the analysis and understanding of the FHRV signal is testified by the large number of studies which deal with FHRV analysis in the time and frequency domain, and by means of nonlinear techniques [3–11], in order to establish diagnostic indexes and/or criteria for the early recognition of foetal distress [12,13], or to investigate factors capable of affecting FHRV, such as gestational age, behavioural states and even gender or time of the day [6,14].

However, there is a high inter and intra-observer variability in the interpretation of FHR signals and, although standard definitions exist for some parameters evaluated on these signals [15,16], there are no clear standards for the definition and evaluation of FHR changes. Various algorithms have been developed to quantify the FHR parameters, but there is no standardisation useful in clinical applications yet [15]. In addition, methods of estimating the FHRV signal and the definition of its power spectral bands are not yet standardised [17–20], despite the widespread use of the FHRV spectral analysis, since the introduction of electronic foetal monitoring [21–23] to improve the diagnosis of foetal pathologic conditions. Most of the literature [24–26] agrees that, as well as for adults, three bands can be detected in the FHR power spectrum: a very low frequency band (VLF), a low frequency band (LF), and a high frequency band (HF). However, there is no agreement as regards the definition of the boundaries of these bands that can be really appropriate for assessing foetal state or development [20,27].

Moreover, differently from the HR signal of the adult, there are transient increases or decreases in FHR, respectively accelerations and decelerations, which make the definition and identification of FHRV more difficult. Some guidelines state that variability refers to the fluctuations in the baseline free from accelerations and decelerations [28]. This can be an important drawback of the above guidelines, since variability in correspondence with these FHR alterations can be significant in terms of the prognostic value [13,29,30].

The aim of this research was to propose the computation of the FHRV signal as the difference between FHR and floatingline, the imaginary median line of the FHR signal [29,31,32] that follows accelerations and decelerations; floatingline and variability, together with other parameters, such as baseline and fluctuations, are significant in antepartum foetal monitoring [31].

The previously proposed software for the estimation of the floatingline [32] was updated and optimized, in order to preserve all the information content of the FHRV signal, and made completely automated.

2. Materials and methods

2.1. Simulated FHR signals

We tested the methodology for the floatingline estimation by using synthetic FHR signals with given characteristics (including a reference floatingline) *a-priori* known.

According to previous works [33–35], FHR signals were generated via software starting from an artificial RR tachogram, with power spectrum characteristics specific for foetal heart rhythm. After RR generation, the FHR signal was computed using the known formula

$$FHR = k/RR,$$

where $k = 60$ if RR is expressed in seconds, or $k = 60{,}000$ if RR is expressed in ms. As default values, mean FHR was set at 140 bpm – beats per minute – (within the range of normality, from 120 to 160 bpm [36]) and its standard deviation (called SDF in order to be distinguished in the following from SD in the statistical description of the results) was set to 2 (corresponding to a peak-to-peak FHR value in the range from 7 to 10 bpm). Then, in order to simulate the reference floatingline (in the following called *ref_float*), we added accelerations and decelerations events. Bearing in mind the definition of accelerations as transient increases of the FHR from the baseline of at least 15 bpm for at least 15 s [30], we simulated the accelerations by using Gaussian-like signal tracts (with different values of the following parameters: amplitude, σ, and duration of the signal tract) [33]. In the same way, we simulated the decelerations, by changing the values of the above parameters. Finally, in order to verify the ability of the estimated floatingline to follow contiguous FHR events, in addition to isolated ones, in some tests we simulated a deceleration suddenly followed by an acceleration to simulate a foetal recovery, i.e. the acceleration after a transient distress elicited by a FHR deceleration, and two very close accelerations.