PRESENCE OF IRREGULARITY IN FETAL HEART PERIOD TIME SERIES

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Abstract: Investigations of fetal heart rate in the course of pregnancy have suggested that its variability may reflect nonlinear processes. In this study we examined 43 fetal RR tachograms derived from magnetocardiographic recordings in 8 healthy pregnancies. Irregularity in the RR interval sequences was quantified with the help of approximate entropy (ApEn). ApEn of the RR interval time series increased with gestational age. The use of surrogate data showed that this increase of irregularity is due to an increase of the nonlinear component in the heart rate. Furthermore, on the basis of a binary representation of the RR tachograms, it could be demonstrated that the dependency on gestational age resulted from the absolute values of the RR interval and not just from the dynamics of lengthening or shortening of the beat period.

Introduction

It has been shown that fetal heart rate variability increases in the course of pregnancy. Furthermore evidence exists that suggests that this variability has a nonlinear component [1]. Aim of this study was to determine, on the basis of surrogate data, whether the complexity found in fetal heart period time series is due to linear or nonlinear processes. To gain further insight into the origins of increasing complexity, a binary representation of the original time series is used. Thus the contribution of dynamical aspects to the observed complexity can be distinguished from the contribution of the full information.

Materials and Methods

We investigated 8 women who presented with healthy singleton pregnancies in the second trimester. Fetal magnetocardiograms were obtained at regular intervals of roughly four weeks up to the time of birth. 43 recordings were acquired between the 16th and 41st week of gestation. Using a 37 channel biomagnetometer (Siemens Krenikon, Erlangen) in a shielded environment, data were acquired for five minutes with a bandpass of 1-200 Hz at a sampling rate of 1 kHz. The RR interval was determined to an accuracy of 1 ms as the time between consecutive QRS complexes.

Two time series were examined per recording: the series of ca. 600-800 RR intervals and the symbolic binary sequence reflecting the increase or decrease in RR interval duration of successive beats. The latter discards the information on absolute RR interval duration while retaining the dynamical aspects of the fetal heart beat. Heart period dynamics was assessed for both series on the basis of the approximate entropy (ApEn) [2-4]. ApEn was calculated for each RR interval series with block lengths of one and two and the radius of 5 ms. ApEn of the symbolic binary sequence was calculated in a similar fashion with the following differences. Because the number of possible binary patterns is considerably lower than the of number possible patterns of consecutive absolute RR intervals, the window length, for which ApEn was calculated, was restricted to 6. Also, the binary nature of the sequences resulted in a radius < 1. The window was moved over the entire binary series and ApEn was calculated for each window. The average binary ApEn was used to quantify the binary sequence.

Surrogate data were generated for each recording by phase randomization of the Fourier transformation followed by an iterative scheme which retains the power spectrum (i.e. the autocorrelations) and the distribution of the original data [5]. Subsequently the surrogate data were analyzed in the same manner as the original data.

Results

The ApEn values of the RR interval time series increased from 0.3 before the 20th week to approximately 0.8 at the end of pregnancy (Fig. 1). Linear regression analysis showed a clear dependency on gestational age (slope = 0.03, r = 0.69). ApEn of the surrogate data showed no such dependency (slope = 0.01, r = 0.26), the values ranging between 0.3 and 1.4.

In contrast to the series of absolute RR interval values, there was no evidence of a relationship between gestational age and binary ApEn of the symbolic binary series, its values laying between 0.31 and 0.46 (Fig. 2). The surrogate binary series also did not show any dependency on gestational age but its values, in a range from 0.35 to 0.50, were consistently higher: the mean difference between the ApEn values of the original and the surrogate binary series was 0.03 ± 0.03 (±SD).

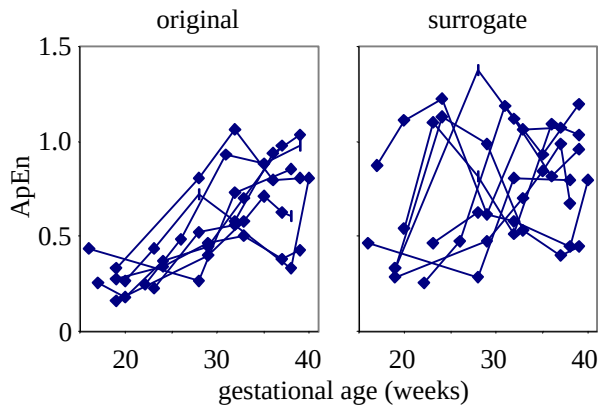

Figure 1: ApEn of original data and surrogate data vs. gestational age.

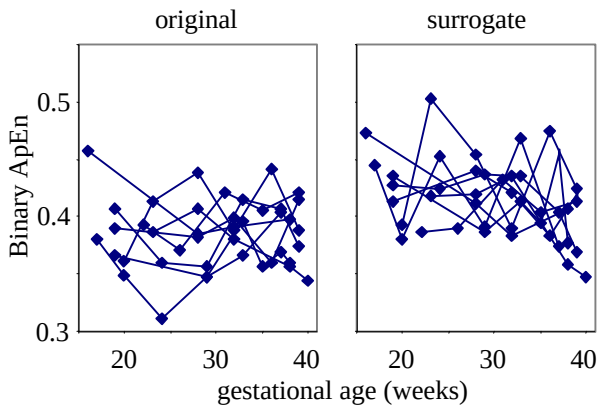

Figure 2: Binary ApEn of original data and surrogate data vs. gestational age.

Discussion

During the second and third trimester of pregnancy, fetal heart rate tends towards lower values. This is accompanied by an increase in heart rate variability. In previous work we have shown that a corresponding increase in heart rate complexity can also be found [1]. The results presented here demonstrate that this irregularity in the heart period sequences can be attributed to a non-linear process. Analysis of the surrogate RR interval series resulted in higher ApEn values and a loss of the dependency on gestational age. As the surrogate data retained the distribution and spectral properties of the original data while randomizing their order, the changes in ApEn in the original data reflect changes in their temporal structure which cannot be attributed to linear properties. One may question whether the increase in irregularity is simply due to the physiological increase in heart rate variability associated with decreases in heart rate or whether it reflects the maturation of the fetal cardiac system.

Analysis of the binary sequences, which reduce the information content of the original RR interval series by converting them into sequences reflecting the increment or decrement of the beat period, led to results which no longer displayed the dependency on gestational age. This indicates that this dependency is related to the absolute values of the beat period. Furthermore, the fact that the analysis of the surrogate binary sequences led to higher ApEn values suggests that, although the relation to age was no longer present, the binary sequences did retain a nonlinear component. If ApEn of the RR interval and its binary sequences can be shown to be stable and reproducible in normal pregnancies, their application may be useful in the identification of pathological conditions.

Conclusions

The increase in complexity of fetal heart period time series during pregnancy can be attributed to an irregular nonlinear temporal structure and is not solely due to linear autocorrelations. Reducing information by constructing time series by binary symbolization which ignore the absolute beat durations resulted in a loss of dependency on gestational age but a retention of irregularity. Therefore the increase of complexity with gestational age can be linked to a nonlinear component embedded in the changes in the absolute values of the RR intervals.

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