Spectral and Fractal Structures of Heart Rate Variability in Coronary Artery Disease Patients without Myocardial Infarction

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Abstract

Heart rate variability (HRV) allows risk stratification in coronary artery disease (CAD) patients, but only few works evaluated HRV in CAD patients with preserved ejection fraction. Aim of this work is to describe spectral and fractal structures of HRV in CAD patients with normal ejection fraction.

We recorded R-R intervals for 15 minutes in 10 CAD patients and in 10 matched controls with the same ejection fraction, estimating broadband power spectra, PSD(f), and the recently proposed temporal spectrum of scale coefficients, $\alpha(\tau)$. In CAD patients, PSD(f) was significantly ($p<0.05$) lower over a low-frequency band (0.047-0.240 Hz) and over a very-low frequency band (0.007-0.022 Hz); $\alpha(\tau)$ was significantly higher between 9 and 25 s (corresponding to low frequencies) but did not differ from controls at scales τ corresponding to very-low frequencies.

Therefore, in CAD patients, even when the ejection fraction is preserved, a low frequency spectral component with its own fractal signature is absent. In addition, fluctuations at lower frequencies are reduced but, in this case, the power reduction is not associated with an altered fractal dynamics.

1. Introduction

Heart rate variability may allow risk stratification in coronary artery disease (CAD) patients. However, few studies only evaluated heart rate variability in CAD patients without myocardial infarction and with preserved ejection fraction. Nevertheless, this evaluation is important also in these patients, because cardiac death may occur without previous events like a myocardial infarction. Thus, aim of this work is to describe possible alterations of the spontaneous heart rate variability in CAD patients without myocardial infarction and with normal ejection fraction.

For this aim, this study will apply "broadband" algorithms of power spectral analysis and fractal analysis that we have previously developed for the analysis of the spontaneous cardiovascular variability.

2 Broadband Algorithm

The following paragraphs illustrate the broadband methods we proposed for spectral and fractal analysis of cardiovascular time series. Since the broadband fractal method is relatively new, its performances are described with an application on healthy volunteers at different levels of activation of the autonomic nervous system.

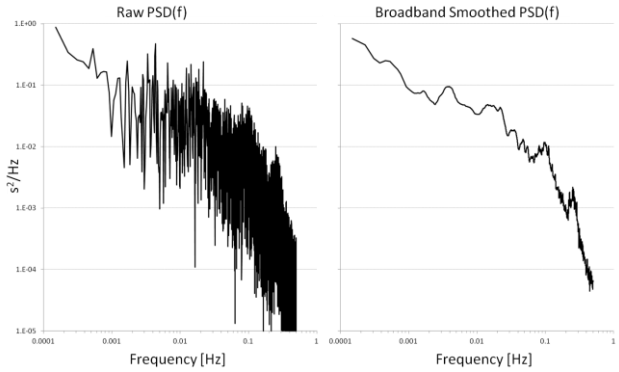

Figure 1. FFT spectrum of R-R intervals before (left) and after (right) a broadband smoothing procedure.

2.1. Broadband Spectral Analysis

The broadband spectral method is a variant of the Daniell's periodogram [1]. The Daniell's periodogram estimates an FFT spectrum over a single data window, and then reduces the estimation variance by smoothing the spectral lines with a moving average filter of order *N*. As *N* increases, the estimation variance decreases but at the cost of a loss in frequency resolution. When cardiovascular time series are analyzed, it is useful to preserve a high frequency resolution at the lowest frequencies and, at the same time, to strongly reduce the estimation variance at the higher frequencies.

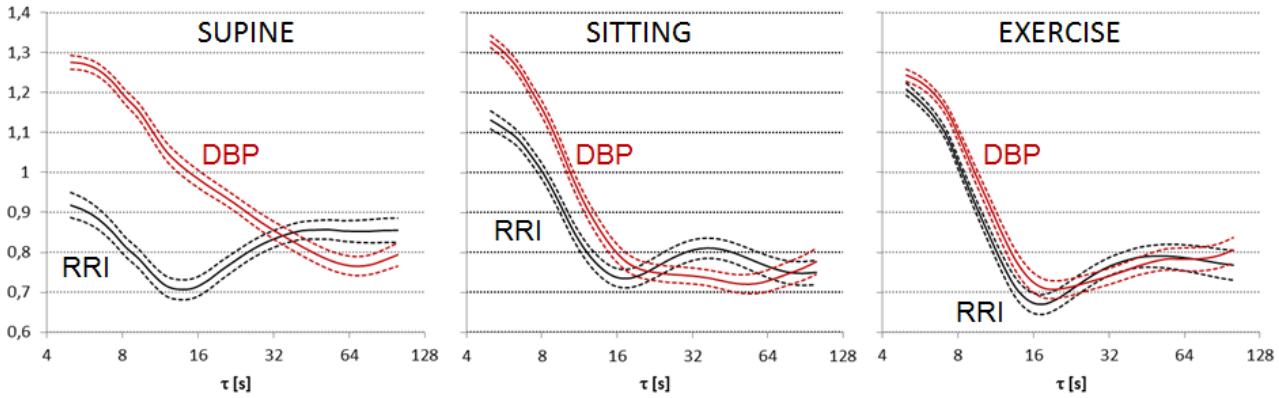

Figure 2. α(τ) of RRI and DBP in healthy volunteers at different levels of autonomic activation (mean ±sem).

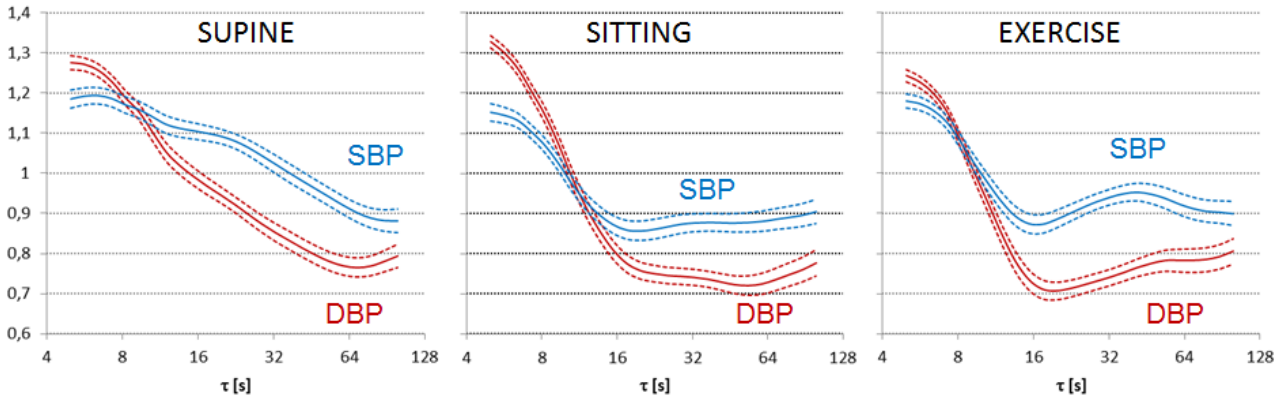

Figure 3. α(τ) of SBP and DBP in healthy volunteers at different levels of autonomic activation (mean ±sem).

To obtain an optimal trade-off between these opposite needs, the broadband spectral approach increases the order *N* of the filter as a power of the frequency *f*:

$$N = a \times f^{b} \qquad (1)$$

It is therefore possible to preserve the desired frequency resolution at the lower frequencies and, at the same time, to decrease substantially the estimation variance at the higher frequencies by selecting properly the *a* and *b* coefficients (see an example in figure 1).

1.2 Broadband Fractal Analysis

The proposed fractal method is an extension of the Detrended Fluctuation Analysis algorithm. This latter is a popular tool for estimating a scale coefficient α strictly related to the Hurst's exponent, the parameter that characterizes the nature of a self-similar time series [2]. The scale coefficient α is estimated as the slope of the regression line between a variability function *F(n)* and the block size *n* over which *F* is calculated, when *F* and *n* are plotted in a log-log scale. However, the heart rate is not a pure monofractal process, and more sophisticated fractal models, with more than one scale coefficients α, have been proposed in the past [3]. Our approach is instead to evaluate a whole spectrum of scale coefficients α(τ) as a function of the temporal scale τ [4]. This fractal spectrum is obtained by calculating the derivative of log *F(n)* vs log. *n* in the beat domain

$$\alpha_B(n_j) = \frac{Log(F(n_{j+1})) - Log(F(n_{j-1}))}{Log(n_{j+1}) - Log(n_{j-1})} \qquad (2)$$

where *j* is the index of successive block sizes, and by converting the beat-domain into the time-domain defining α(τ) as:

$$\alpha(\tau) = \alpha_B(n) \text{ for } \tau = n \times \mu_{RRI} \qquad (3)$$

with μ_{RRI} the average R-R interval (RRI).

To illustrate the performances of α(τ) in characterizing the autonomic cardiovascular regulation, we applied it to analyse beat-to-beat time series of RRI and of systolic and diastolic blood pressure (SBP and DBP) recorded

previously in healthy volunteers for 10 minutes at rest in supine position (SUPINE), sitting at rest (SITTING), and sitting while performing a light physical exercise (EXERCISE) [3]. The RRI dynamics is mainly modulated by the cardiac vagal outflow and by the cardiac sympathetic outflow, while the DBP dynamics is expected to be modulated mainly by changes in vascular resistances, that in turns are modulated by the vascular sympathetic outflow. Since the vagal outflow on the heart is higher and the sympathetic outflow on the heart and on the vessels is lower during supine rest, one should expect differences in the RRI and DBP fractal dynamics in supine rest. Actually, the $\alpha(\tau)$ spectra of RRI and DBP differ importantly in SUPINE (figure 2, left). The vagal outflow on the heart decreases and the sympathetic outflow on the heart and vessels increases changing posture from supine to sitting, and coherently the differences between the RRI and DBP fractal spectra decrease in SITTING (figure 2, centre). Finally, during a physical exercise one should expect the lowest vagal outflow on the heart and the highest sympathetic outflow on both the heart and the vessels: actually $\alpha(\tau)$ of RRI and DBP practically coincide in this condition (figure 2, right). The SBP dynamics is expected to depend not only on vascular resistances modulations, as for DBP, but also on modulations of cardiac output. This could be the reason why the SBP fractal spectrum is higher than the DBP spectrum for scales larger than 10 s in all the three conditions (figure 3).

2 Data Collection

We enrolled 10 male CAD patients and 10 male controls matched by age, ejection fraction, body mass index and blood pressure levels (table 1). The ECG was recorded for at least 15 minutes in supine position. Beat-by-beat RRI time series were analyzed by broadband spectral and fractal analysis over selected stable segments of 14 minutes.

Table 1. Characteristics of patients and controls: mean (SD)

	CAD	Controls
Age (years)	58.4 (5.4)	64.0 (6.5)
Ejection Fraction (%)	59.0 (2.4)	59.1 (5.2)
BMI (kg/m^2)	24.9 (2.1)	24.6 (1.6)
SBP (mmHg)	124 (14)	126 (7)
DBP (mmHg)	76 (5)	82 (6)

BMI= Body mass index

3 Results

The power spectrum was significantly lower ($p<0.05$) in CAD patients over two separate bands: a low frequency band centred around 0.1 Hz and a very low frequency band centred around 0.01 Hz. In particular, the 0.1 Hz peak, that characterizes the low frequencies of controls, does not appear in the power spectrum of CAD patients.

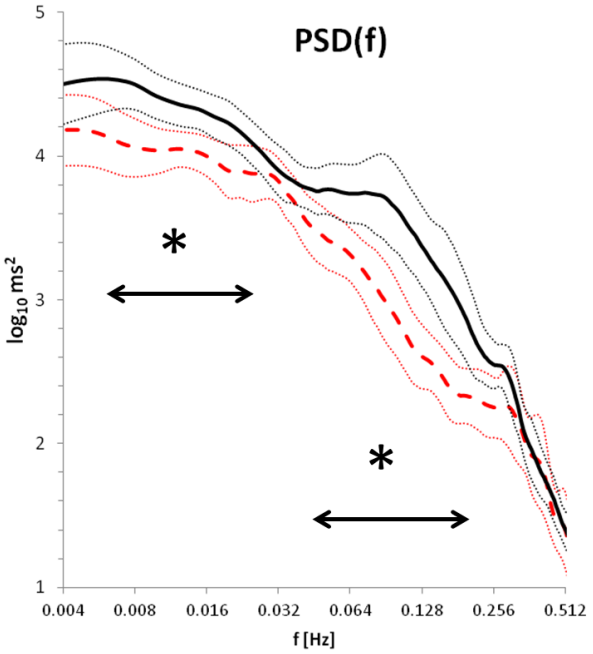

Figure 4. Broadband power spectra of RRI in CAD patients (dashed red line) and controls: mean ±sem. Asterisks indicate bands where spectra differ at $p<0.05$.

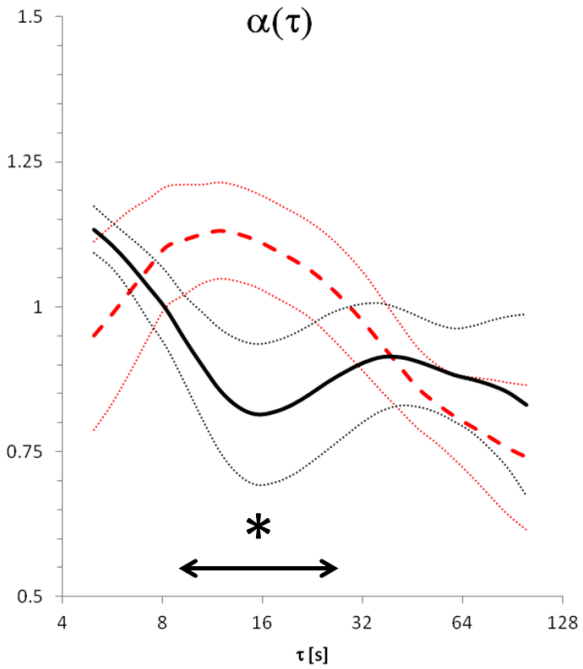

Figure 5. Temporal spectra of RRI scale coefficients in CAD patients and controls (see figure 4 for symbols).

By contrast, the spectrum of scale coefficients was significantly higher in CAD patients over a single temporal band, between 9 and 25 s. This temporal band corresponds to the low-frequency band were power spectral components were lower in CAD patients. It should be also noted that no changes in fractal scale coefficients were found at scales around 100 s. These are the temporal scales corresponding to the very low frequency band where power spectral components appeared to be significantly reduced in CAD patients.

4. Discussion

We showed that CAD patients, even without a previous myocardial infarction and with normal ejection fraction, have altered power spectra and fractal spectra of heart rate variability. While spectral estimates at the very-low frequencies or very-long scales indicate a decreased variability without structural changes in the RRI dynamics, estimates at 0.1 Hz or 10 s indicate the disappearance of a specific component of variability, with its own "fractal signature".

These results strongly suggest the presence of an impaired baroreflex gain. In fact, an impaired baroreflex could be responsible for a lower sensitivity of heart rate to blood pressure changes in the very-low frequency band, and for the disappearance of a specific component of cardiovascular variability, the so-called "ten seconds oscillation", that is generally assumed to be due to a resonance in the baroreceptors reflex [5]. Interestingly, a recent study based on stimulations of the baroreflex control by a neck-suction device, reported a reduced baroreflex gain in CAD patients with preserved ejection fraction, supporting this interpretation [6].

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