Modifications in the Heart Dynamics of Patients with Cardiac Disease

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Abstract

We know, nowadays, that the dynamics of cardio respiratory system is extremely complex and chaotic. Any modification in the systems dynamics can be a sign of a disease. This work investigates the presence of modifications in the dynamics of the cardiac rhythms through the observations in the dynamics of the attractor built from RR series. For each series, the decorrelation time was measured in order to obtain the delay time and, then, to reconstruct the attractor. In order to estimate nonlinear parameters, the existence or not of stationarity was investigated through tests that utilize the surrogate procedure. The parameter chosen here is the Correlation Dimension, because it can be interpreted as an indicator of the degree of system's organization. In this way, the more complex is a system, the greater is its Correlation Dimension. That was exactly what we got: the correlation dimension is significantly smaller in the group of man with cardiac disease.

1. Introduction

The variability of the cardiac rhythm outside its normal limits or the appearance of new rhythms where there was no previous rhythm is associated with illness. The investigation of the modifications in the dynamics of the heart with some cardiac disease compared with the dynamics of the healthy heart, can bring some light in the diagnostic and, probably, in the therapeutics [1].

This work deals with some modifications in the heart behavior that can be find looking at the fractal attractor, built from the RR series; more specifically, looking at de dimension of the attractor. Nowadays, the most popular measure of the fractal dimension in time series is the Correlation Dimension (CD). The algorithm used here was proposed by Grassberger and Procaccia in 1983 [2]. The fractal dimension can be interpreted as an indicator of the degrees of freedom of the system and is a measure of the complexity of the system: more complex systems have greater fractal dimension [3-5].

Takens showed, in 1981 [6], that it is possible to reconstruct the dynamic of a system starting from just one variable and, at the same time, preserve some properties of the it. The algorithm is based in the construction of m-dimensional vectors starting from the time series, where *m* is the embedding dimension. Takens´s theorem assure that there is a representation of the system in a rebuilt space, using $x(t_i)$ as first coordinate, $x(t_{i+\tau})$ as a second coordinate and $x(t_{i+m\tau})$ as the last coordinate, where τ is the time lag (or reconstruction step).

In order to choose the suitable value of m, the reconstruction should be made for successive and crescent m values (m = 2, 3 …). An attractor of topological dimension D_0 should be embedded in a space of dimension m not smaller than $2D_0+1$ (otherwise the attractor will appear folded over itself and distant points will become neighbors, generating a distortion in the parameter measured.

A cell centralized in each point of the attractor is built and the probability of the occupation of this cell is computed. The value of CD is found based in the probability of the existence of two points of the attractor in a circle of radius ε, for instance. The measure of this probability is known as the Correlation Integral. The Correlation Integral is a function of ε and can be expressed by equation (1):

$$C(\varepsilon) = \lim_{N\to\infty} \frac{1}{N(N-1)}$$

$$\left\{ n^o \text{ pairs } i, j, \text{ so that} | \mathbf{x}_i - \mathbf{x}_j | < \varepsilon \right\} =$$

$$= \frac{1}{N(N-1)} \sum_{i=1}^{N} \sum_{j=1}^{N} \Theta\left[\varepsilon - | \mathbf{x}_i - \mathbf{x}_j |\right] \qquad (1)$$

Where $\Theta(x)$ is the Heaviside Step Function:

$$\Theta(x) = \begin{cases} 1 & if \quad x \geq 0 \\ 0 & if \quad x < 0 \end{cases}$$

Essentially, C(ε) is a measure of probability and grows exponentially. Therefore, in a log-log scale, the graphic of C(ε) against ε, shows a linear region where:

$$\log\ (C(\varepsilon)) \approx CD.\log\ (\varepsilon)$$

is satisfied and the Correlation Dimension is computed as:

$$CD = \lim_{\varepsilon \to 0} \frac{\log C(\varepsilon)}{\log \varepsilon} \qquad (2)$$

Theiler [7] proposed the generation of surrogate data sets from original data. These surrogate data would have the same linear properties than the original data, but would have been randomized enough to remove nonlinear relations.

Stationarity means that the statistical properties like mean and variance in the time domain, as well as the power spectra in the frequency domains, did not change during the randomization process.

The main goal of the present work is to evaluate some differences between two groups of individuals, one composed of healthy individuals and the other composed of individuals with some cardiac disease, regarding the Correlation Dimension parameter.

2. Methods

We used time series obtained from twelve healthy male volunteers (32 ± 8.1 years) and sixteen male volunteers with some cardiac disease (Chagas´ disease) (37 ± 9.9 years). None of them was taking any medicine that could interfere in the autonomic control of the heart. All the series were collected at the same period of the day, to avoid changes in their standards due to biological rhythms. The variable recorded were the RR intervals (in milliseconds), in the rest position, each one lasting for a little more than fifteen minutes. Specific software was used to detect R waves of ECG signals and the respective periods [8-9]; the RR interval were then obtained.

The computational programs written were fed by the original RR intervals time series, dropping out the first and the final 1.5 minutes (leaving around fifteen minutes net) in order to assure a stability period for the studied signal.

At first, a conventional statistical analysis was done regarding the variability of the RR intervals. In order to estimate nonlinear parameters, the existence or not of stationarity was investigated through tests that utilize the surrogate procedure. For the nonlinear analysis, the fractal Correlation Dimension (CD) was estimated for each of the series. The outcomes of the analysis were then compared using suitable statistical tests.

3. Results

The comparisons between the two groups made through linear parameters did not reveal any statistically significant difference. The average RR interval for the healthy group is slightly smaller than the average of the group with cardiac disease (961.5770 ± 169.4639 and 982.5970 ± 157.7887, respectively), but this difference is not statistically significant ($p>0.05$).

The linear parameters as average, standard deviation and median did not change after the randomization of the series (surrogates). This test for nonstationarity was made for one series of each group. The series revealed being stationary.

The CD was the parameter chosen for the nonlinearity test. An important parameter evaluated in order to compute the CD was the time lag τ (table 1), also used as an diagnostic indicator [10]. It was evaluated as the first minimum of the autocorrelation function, as displayed in figure (1).

Table 1. Values of τ (time lag) for the two groups.

Health	τ	*Disease*	τ
AVS	6	ACM	2
DF	2	AVMR	2
EB	6	EGP	8
ECR	5	FGS	4
FMN	5	GGF	6
JAA	3	GLC	4
JAM	4	JAAP	9
JCC	7	JBP	4
JLS	3	JCG	9
JorLS	4	JRS	14
LCSC	5	LUC	5
MF	5	MBS	3
MM	6	MPT	2
		NBJ	6
		PFC	2
		NDS	2

The CD was estimated looking at the linear region of the correlation integral graphic, figure (2), for different values of the embedding dimension (m). The values for the CD were found computing the slope (d) of the many lines using linear regression of the points in that region.

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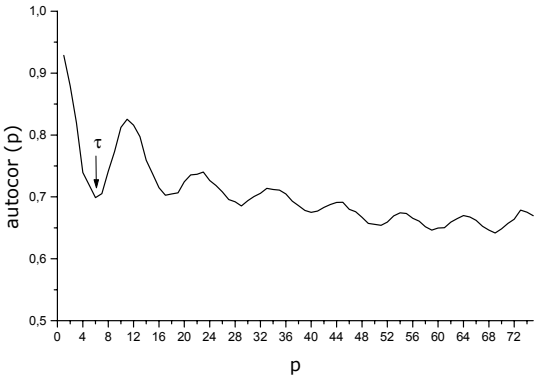

Figure 1. Autocorrelation function for one of the individuals of the healthy group.

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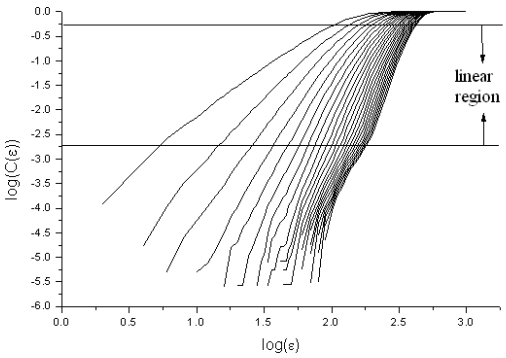

Figure 2**.** Correlation Integral for one of the individuals of the group with cardiac disease.

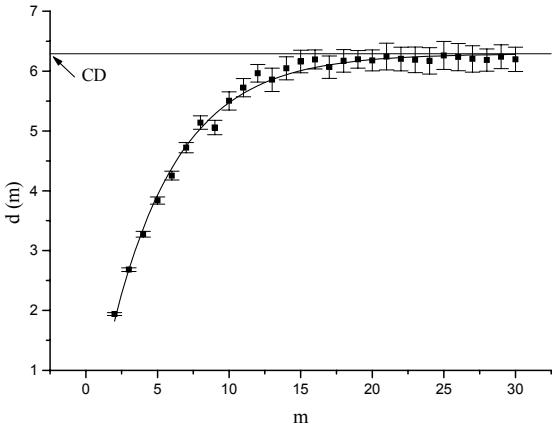

Figure 3**.** Correlation Dimension for one of the individuals of the group with cardiac disease.

With these values for d, new graphics were built, for *d* against *m*, displaying the convergence value obtained through an exponential setting, as can be seen in figure (3): this value is the CD. The values obtained for both groups are displayed in the tables (2) and (3).

Table 2**.** Correlation Dimension for the healthy group.

Health	CD ± sd
AVS	6.98591 ± 0.03881
DF	8.25854 ± 0.18968
EB	7.79478 ± 0.07493
ECR	8.03467 ± 0.09125
FMN	7.62884 ± 0.05349
JAA	9.68511 ± 0.21045
JCC	8.88446 ± 0.11888
JLS	12.22335 ± 0.03342
JorLS	6.98365 ± 0.06185
LCSC	10.75971 ± 0.86805
MF	13.11471 ± 0.52518
MM	9.22024 ± 0.11288

Table 3**.** Correlation Dimension for the group with cardiac disease.

Disease	CD ± sd
ACM	4.78307 ± 0.06422
AVMR	Did not converge
EGP	4.61224 ± 0.04324
FGS	6.7824 ± 0.29502
GGF	6.74041 ± 0.08518
GLC	8.33227 ± 0.287
JAAP	8.08105 ± 0.08334
JBP	6.45376 ± 0.04585
JCG	Did not converge
JRS	3.56783 ± 0.05068
LUC	6.28988 ± 0.0297
MBS	8.34649 ± 0.07407
MPT	6.71989 ± 0.05307
NBJ	6.73191 ± 0.11459
PFC	Did not converge
NDS	Did not converge

4. Discussion and conclusions

Our conclusions can be summarized as follows: the conventional statistical analysis was not able do establish a statistically significant difference ($p>0.05$) between the two groups. The system showed itself to be stationary and nonlinear. Through the nonparametric Mann-Whitney test, we could see a statistically significant difference ($p = 0.0015 \rightarrow p<0.01$) between the two groups, regarding the

Correlation Dimension: the CD is significantly smaller in the group with cardiac disease. As the CD diminished in the group with cardiac disease, it is possible to think that the complexity of cardiac dynamics is smaller in this group compared to that of the normal group. This result agrees with other previously found in the literature, as can be seen, for instance, in Carvajal [11]. This difference means that the heart dynamics of man with cardiac disease is not only different from the heart dynamics of healthy individuals, but that it is different in the sense that the diseased heart loses degrees of freedom.

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