Hurst Exponent for the Analysis of Atrial Fibrillation Recurrence after Ablation Procedures

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Abstract

The aim of this work is to improve atrial fibrillation (AF) dynamics understanding through predicting the reversion to sinus rhythm (SR) in the procedures of ablation. Database includes intracardiac recordings from 42 paroxysmal and persistent AF patients submitted to an ablation procedure. Four electrodes were located at the right atrium (RA) and 4 more at the left atrium (LA). All patients were monitored after ablation: 26 of them remained in SR, where 42.3% were in AF persistent (n=11) and the other 16 turned back to AF, where 43.7% were in persistent AF (n=7). Generalized Hurst Exponent has been applied in order to extract self-similarity of atrial time series. Results showed regional differences in both groups. In patients with non-recurrences in AF mean Hurst Exponent in the LA was 0.65 ± 0.16 *vs.* 0.72 ± 0.08 *in the RA (p=0.017). Nevertheless, non-differences between both atria were found in AF recurrent group (LA* 0.66 ± 0.09 *vs. RA* 0.67 ± 0.10*, p=0.691). Moreover, findings show atrial region similarities between paroxysmal AF and non-recurrence AF patients; nevertheless non-differences between both atria were found in persistent AF group. it highlights the potential of non-linear methods of analysis to study AF dynamic.*

1. Introduction

With the appearance of atrial fibrillation (AF) ablation in medical practice, the managing of this arrhythmia, considered to be incurable, has changed from a strategy directed to avoid tachycardia, merely reducing heart rate, and embolism through anticoagulation, to search the cure of the disease modifying the arrhythmic substrate. The aim of this work is to improve AF dynamics understanding through predicting the reversion to sinus rhythm in the procedures of ablation.

Heart is a complex system and its behavior is non-linear during some arrhythmias. Self-similar or self-affine structures are widely presented in all areas of the nature science [1]. Self-similarity means that each segment of the initial set has the same structure as the whole object. The properties of such systems can be described by special parameters, like fractal dimension (or set of dimensions in case of complex structures [2]) or Hurst exponent [3, 4]. Morphologies of signals can appear to be quite different depending on the scale with which they can be observed [5].

Fractals are fit for signal modeling in the real world, such as electroencephalograms (EEG), electrocardiograms (ECG), as well as other objects which represent some of many natural phenomena and are difficult to be characterized using traditional signal processing theory [6–10]. Physiologic signals generate complex fluctuations in their output signals that reflect the underlying dynamics [11–17]. The main features of these physiologic time series reflects non-stationarity, non-linearity and non-equilibrium, phenomenas that characterizes AF.

In previous studies, non-linear measurements have been employed to study the non-stationary behavior of cardiac signals [18–20].In the proposed article, the data of the diseased patients are collected from patients suffering AF previous ablation procedure. Our calculations are based on the algorithm of generalized Hurst exponent analysis. This parameter determines whether the time series is monofractal or multifractal. The value of this parameter is associated with the scaling of the absolute spread in the increments. The goal of this study is to predict AF recurrence applying this algorithm.

2. Materials

The database includes intracardiac recordings from 42 paroxysmal and persistent AF patients submitted to an ablation procedure. Four electrodes were located at the right atrium (RA) and 4 more at the left atrium (LA).

Intracardiac recordings during AF before ablation procedure, were taken from 42 AF patients (24 paroxysmal AF and 18 persistent AF). The main age was $50.72 \pm$

12, 15 years, 73% male, and mean left atrial size was 44.5 ± 9.8mm. In the paroxysmal AF group, a 24-pole catheter (Orbiter, Bard Electrophysiology, 2-9-2 mm electrode spacing) was inserted through the femoral vein and positioned in the right atrium (RA) with the distal dipoles into the coronary sinus (CS) to record left atrial (LA) electrical activity as well. The medium and proximal group of electrodes were located spanning the RA free-wall peritricuspid area, from the coronary sinus ostium to the upper part of the interatrial region. Using this catheter, 12 bipolar intracardiac electrograms from the RA (dipoles from 14-15 to 23-24) and LA (dipoles 1-2, 3-4 and 5-6), were digitally recorded at 1 kHz sampling rate (16 bit A/D conversion; Polygraph Prucka Cardio-Lab, General Electric). Thirty to 60 seconds recordings from paroxysmal and persistent AF patients were analyzed and compared. Four of these electrodes were located at the RA and 4 more at the LA were analyzed. All patients were monitored after ablation, and were divided in 2 groups according to AF recurrence outcome: 26 remained in SR where 42.3% were in AF persistent (n=11) and the other 16 turned back to AF, where 43.7% were in persistent AF (n=7).

3. Methods

The traditional Hurst exponent, originally developed for monofractal series, has been generalized and used to parameterize scaling heterogeneity (multifractality). In this study generalized Hurst exponent approach (GHE) is used for detection of multifractality [21]. It is based on scaling of q-th order moments of the distribution increments of the process $X(t)$ [5, 22], which is a good characterization of the statistical evolution of a stochastic variable $X(t)$.

The GHE can be defined from the scaling behavior of $K_q(\tau)$ [5], which can be assumed to follow the relation:

$$K_q(\tau) \approx (\tau/\nu)^{qH(q)} \tag{1}$$

The scaling is characterized on the basis of the statistic $K_q(\tau)$, which is defined as $\langle|X(t{+}\tau){-}X(t)|^q\rangle/\langle|X(t)|^q\rangle$ (with t = ν, 2ν, ..., kν, . . . , T) scale with the time-resolution (ν) and the observation period (T), where the time interval τ can vary between ν and τ_{max}.

It is possible to distinguish between two kinds of processes: (1) a process where $H(q) = H$ is constant independent of q; (2) a process with $H(q)$ is not constant. The first case is characteristic of uni-scaling or uni-fractal processes and its scaling behavior is determined from a unique constant H that coincides with the Hurst exponent. This is for instance the case for self-affine processes where $qH(q)$ is linear ($H(q) = H$) and fully determined by its index H. In the second case, when $H(q)$ depends on q, the process is commonly called multi-scaling (or multi-fractal) [23,24] and different exponents characterize the scaling of different $q-$moments of the distribution.

For some values of q, the exponents are associated with special features. For instance, when $q = 1$, $H(1)$ describes the scaling behavior of the absolute values of the increments. The value of this exponent is expected to be closely related to the original Hurst exponent, H, that is indeed associated with the scaling of the absolute spread in the increments.

4. Results

In order to study the multifractal behavior of the AF patients electrograms, Hurst exponent methods were applied. Figure 1 represents GHE from RA dipole time series from a non recurrent AF patient and Figure 2 shows GHE from a RA dipole time series in a recurrent AF patient.

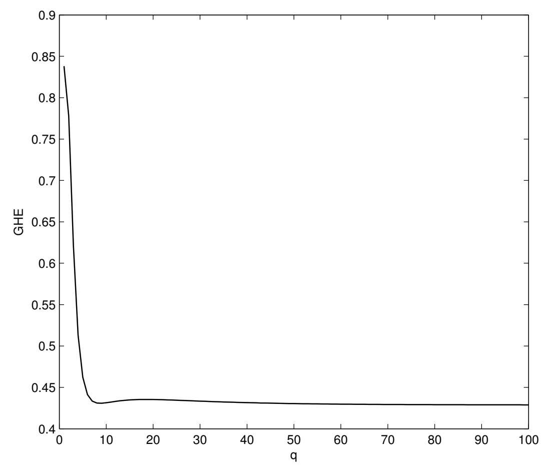

Figure 1. The generalized Hurst exponent $H(q)$ of a non-recurrent AF patient right atrial electrogram time series.

As shown in Figure 1 and Figure 2, relation between $qH(q)$ and q in AF electrocardiograms show a non-linear trend, therefore atrial time series show multifractal in nature.

Since Hurst coefficient is supposed to provide a measure of trending characteristic in a time series, we tried to analyze correlation between Hurst coefficient and different regions from the trend based trading rule. Therefore, different regions were analyzed in recurrent and non recurrent AF groups separately.

4.1. Regional atrial differences results

Results for $q = 1$ showed differences in both atria between both groups. In the recurrent group, non-statistically significant differences between both atria were found, in the LA GHE was 0.66 ± 0.09 vs. 0.67 ± 0.10 in the RA (p=0.691) (Figure 3), although in the non-recurrent group

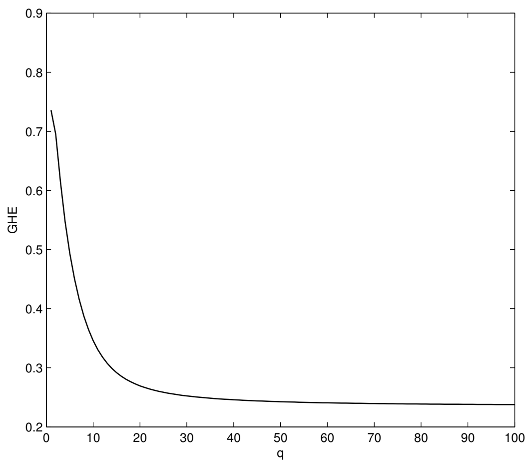

Figure 2. The generalized Hurst exponent $H(q)$ of a recurrent AF patient right atrial electrogram time series.

the differences between both atria were statistical different, with a GHE value of 0.65 ± 0.16 in the LA vs. 0.72 ± 0.08 in the RA p=0.017 (Figure 4).

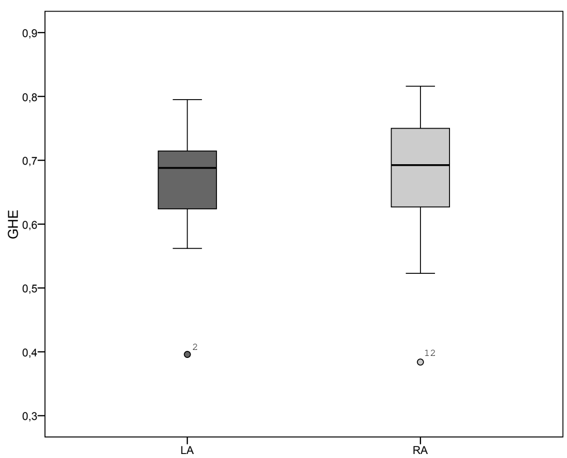

Figure 3. GHE along the atria in recurrent group.

Moreover, statistical significant differences were found between in both atria in paroxysmal AF patients (LA 0.69 ± 0.10 vs. RA 0.73 ± 0.07, p=0.045), although non-differences between both atria were found in persistent AF group (LA 0.65 ± 0.11 vs. RA 0.68 ± 0.12, p=0.325).

5. Conclusion

Ablation therapies to finish AF have their limitations, including failure rates and recurrences [25]. Certainly, the results described above provide some predictive information regarding the recurrence outcome after 3-months follow-up. Although these results are rather complex and

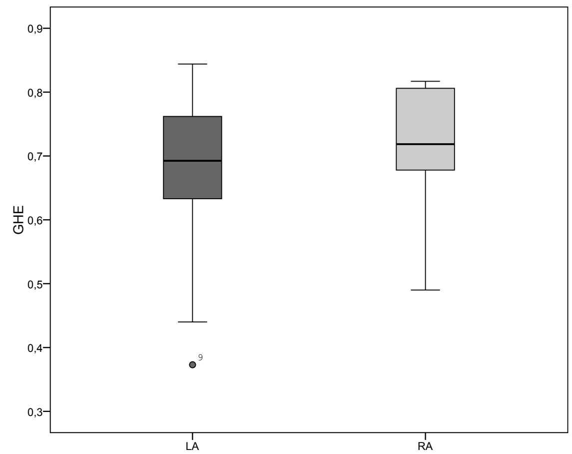

Figure 4. GHE along the atria in non-recurrent group.

not easy to interpret, it can be inferred that patients that remained in sinus rhythm presented different GHE values along the atria than those who turned back to AF.

The search for predictors of AF ablation success and AF recurrence is currently of high clinical interest. Just to mention few recent works, the dominant atrial frequency has been reported to play a role as a predictor of AF ablation outcome [26]. Furthermore, multivariate analysis also showed that larger LA diameter and the presence of RA non-pulmonary veins ectopy during the procedure can predict late recurrence during long-term follow-up [27]. This is still a difficult and non-solved task and, with all its limitations and this paper brings to light the potential of non-linear methods as tool to study atrial activity dynamic during AF.

Indeed, patients within the non-recurrent AF group had higher GHE values in the right chamber, i.e. the atrial activation in the right atrium in this group shows higher autocorrelations of the time series, where GHE values exhibited a LA to RA gradient. All these results are consistent and suggest that low autocorrelated time series in RA and in the rest of the atria could be a pro-arrhythmic indicator and be related to AF drivers or AF maintenance and perpetuation. This means, in turn, that patients with a more chaotic atrial electrical activity along all the atria will have a higher risk to AF recurrence.

In addition, these findings show atrial region similarities between paroxysmal AF and non-recurrence AF patients; and regarding arrhythmia type, GHE was lower for persistent AF patients. it highlights the potential of non-linear methods of analysis to study AF dynamic.

As conclusion, the application of non-linear methods in AF intracardiac electrograms can prognosticate AF recurrences after successful ablation of pulmonary veins. This suggests that when the atrial electrical activity is more irregular and similar in both atria, the reversion to sinus rhythm is more difficult, where higher hurst exponent values, specially at the RA, are associated with sinus rhythm maintenance.

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