Autocorrelation Function for Predicting Arrhythmic Recurrences in Patients Undergoing Persistent Atrial Fibrillation Ablation

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Abstract

Persistent atrial fibrillation ablation has a high recurrence rate. In this work, we performed an analysis of bipolar intracavitary signals obtained with a conventional 24-pole diagnostic catheter (Woven Orbiter) placed in the right atrium and coronary sinus in a cohort of patients with persistent atrial fibrillation undergoing ablation to detect features predictive of acute procedural success (conversion to sinus rhythm during ablation) and the occurrence of recurrences. The goal is to arrive at a quantitative description of the degree of randomness of the atrial response in atrial fibrillation and to demonstrate the presence of hidden periodic components. This was done by the determination of the autocorrelation function. Results showed that higher correlation in relative maximum peaks, and a lower dominant atrial frequency (greater distance between relative amplitude maxima) may be associated with a greater likelihood of achieving reversion to sinus rhythm and lower probability of recurrences. A larger study is needed to draw conclusions.

1. Introduction

Atrial fibrillation (AF) is the most frequent arrhythmia with a significant morbidity associated with symptoms, heart failure and thromboembolism, which are associated with excess mortality [1]. In addition, AF naturally progresses to persistent AF in an estimated 15-30% over 1-3 years, with a consequent increase in risks and complications [2–4].

In recent years, ablation of paroxysmal atrial fibrillation has become a treatment with high success rates and few complications, compared to conventional treatment with anti-arrhythmic medication, in terms of arrhythmia recurrence, quality of life and arrhythmia progression.

AF ablation is currently one of the fastest growing techniques in cardiology and, given the large number of AF patients who may be candidates for this intervention. An optimal ablation strategy that can be successfully applied to all forms of AF, from paroxysmal to permanent, has not yet been defined. Pulmonary vein isolation or circular pulmonary vein ablation has emerged as an optimal alternative to chronic arrhythmic drugs in patients with paroxysmal AF, since a significant number of AF episodes start in the PV area, and the effectiveness of these techniques in these patients is 70-90%, however, in patients with longstanding persistent AF, ablation is more complex, often requiring repeated interventions to achieve success rates as high as in paroxysmal AF [5–8].

The electrophysiological determinants responsible for increased susceptibility to AF are incompletely understood and poorly characterized. As a result, therapy remains largely empirical and plagued by relatively low efficacy. Additionally, the risks of proarrhythmia associated complicate the management of patients with AF.

Theoretical formulations and high-density mapping studies have suggested that the electrophysiological mechanism responsible for the maintenance of AF is the presence Therefore, the repetitive activation patterns emanating from focal activation sources played a critical role in the maintenance of AF, nevertheless there is controversial about multiple wandering wavelets circulating throughout the atrial tissue or repetitive activation patterns were observed at all times [9–12]. Moreover, previous studies have confirmed that susceptibility to sustained AF can be quantitatively characterized by the magnitude of the tissue wavelength [13].

Then, in this work we propose to detect atrial sites with more ordered activation sequences, where the autocorrelation function is used to extract features and observe how sequential observations in a time series affect each other.

2. Materials & Methods

We performed an analysis of bipolar intracavitary signals obtained with a conventional 24-pole diagnostic catheter (Woven Orbiter) in a cohort of consecutive patients with persistent AF undergoing pulmonary vein ablation plus drivers (regions with continuous electrical activity and regions with spatio-temporal dispersion and fragmentation), to detect features predictive of acute procedural success (conversion to sinus rhythm during ablation) and the occurrence of recurrences.

For each dipole, autocorrelation function was analysed, comparing consecutive electrograms and establishing the degree of similarity between. 31 patients included (77%male; left atrial index volume 38±17ml/m^2; 10 with previous ablations). Ablation achieved reversion to sinus rhythm in 12 patients (39%). After a mean follow-up of 15±8 months, 10 patients (32%) had arrhythmic recurrence, excluding 3-month blanking (Table 1).

A 12-bipolar catheter (Orbiter PV, Bard Electrophysiology, Lowell, MA, USA; 2–9–2 mm electrode spacing) was inserted through the femoral vein and positioned in the right atrium (RA) with the medium and proximal group of electrodes located spanning the RA free-wall peritricuspid area, from the coronary sinus ostium to the upper part of the interatrial region left atrial (LA) electrical activity as well. Twelve bipolar intracardiac electrograms of the sequences of activation over 60 seconds were digitally recorded at 1 kHz sampling rate (16 bit A/D conversion; Polygraph Prucka Cardio-Lab, General Electric, Piscataway, NJ, USA). In 2 patients, the length of electrograms recorded was insufficient and were discarded.

Table 1. Characteristics of Participants at Baseline.

	Gender	
	Men	Women
Participants	24	7
Age	43.4±10.5	48.7±8.7
LA volume (ml/mm^2)	37.92±19.02	38.14±11.35
Heart disease	10 (41.70%)	4(57.10%)
Successful ablation	8 (33.33%)	4 (57.10%)
AF Recurrence	7 (29.16%)	3 (42.90%)

For each dipole data recording, a preprocessing step was applied [14] and autocorrelation function was was applied to each recording. Autocorrelation is a statistical method that can measure internal correlation within a time series domain. Autocorrelation also known as "serial correlation" or "lagged correlation" is a statistical method that measures dependency of variables arranged in time. It is defined based on the concept of time lag. Performing autocorrelation of a time series data is beneficial especially to identify signal stationary condition, measure variability level of continuous data or even indicate quantitative relation of some previous data points occurring with a time lag.

In this study, autocorrelation function was be used to measure variability level of serial correlation of atrial electrogram data, peak value and time location of the first periodic slope.

The value of the function F(t) in the i^{th} interval will now be called x_i, where x_i is either zero or unity.The time lag τ is similarly introduced in discrete steps $\tau = k\Delta t$, the values of F(t + τ) are consequently x_{i+k}. The approximate autocorrelation function will then be:

$$R'(\tau) = \frac{1}{T}\sum_{i=1}^{N} x_i x_{i+k}\Delta t \tag{1}$$

However, there is a common characteristic shared among this arrhythmia, which is the irregularity in shape that appears in time series domain. In this work, a quantitative analysis is proposed to numerically characterize the two parameters, which come from the first periodic slope of autocorrelation result.

The goal is to find structure in these observations, then it is likely to help us improve the accuracy of our forecasts. This will lead to greater profitability in our trading strategies in order to predict successful ablation intervention approaches.

3. Results

Results showed that the RA and coronary sinus ostium electrograms of patients with reversion to sinus rhythm during ablation had a higher correlation between the amplitude of successive electrograms (more similar voltage), and a lower frequency (greater distance between relative amplitude maxima), with no significant differences due to the small sample database size. The same behavior was observed in patients without arrhythmic recurrences with respect to those with recurrences (Figure 1 and Figure 2) .

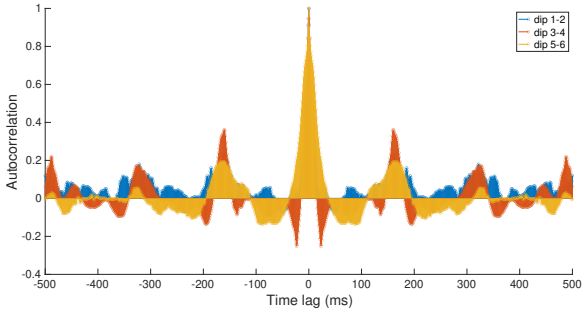

Figure 1. Correlation along coronary sinus in a patient with AF recurrence

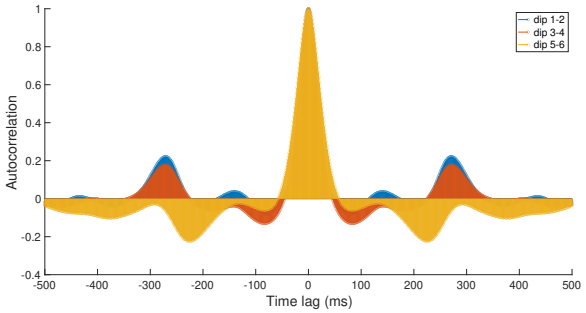

Figure 2. Correlation along coronary sinus in a patient that maintenance sinus rhythm.

The autocorrelation function computed the correlation between two series of data, one being the original electrogram, the other the same electrogram with a time scale shifted by various values of τ. The results interpretation can be helpful to understand the atrial wave dynamic. Figure 3 shows a close time series of a periodic signal, then the autocorrelation function is also a periodic function with the same period. Furthermore, if the given function is a mixture of periodic events and non-periodic events, the autocorrelation function may have the form of a decreasing exponential, where the coefficient of the exponential may represent the degree of arrhythmia (Figure 4). We note immediately that several degrees of arrhythmia are present. Although we began by considering the alternative: periodicity versus irregularity, we can now clearly observe that the arrhythmia found in atrial fibrillation is a matter of degree.

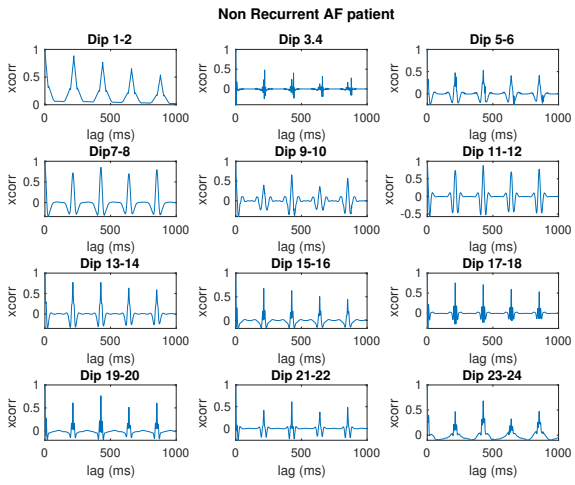

Figure 3. Autocorrelation of 12 dipoles located in the LA and the RA from a patient with non-recurrent AF .

Morever, it was observed that in those patients in whom ablation success was achieved, the amplitude of the relative maximum of the autocorrelation function was 0.48 ± 0.17 vs. 0.33 ± 0.16 0.42, in patients in whom electrical cardioversion was required for passage to sinus rhythm during ablation. Furthermore, in the patients in whom ablation was unsuccessful, a greater distance from the first relative maximum was also found with 239 ± 97 ms vs. 182 ± 36 ms, in the patients in whom ablation success was achieved. On the other hand, the amplitude of the relative maximum of the autocorrelation function was 0.53 ± 0.07 in those patients without recurrences in the arrhythmia vs. 0.39 ± 0.21, in patients with AF recurrence. Moreover, in these patients with AF recurrence a greater distance from the first relative maximum was also found, compared to the patients that maintenance sinus rhythm, 229 ± 76 ms 188 ± 35 ms, but the differences were not statistically significant.

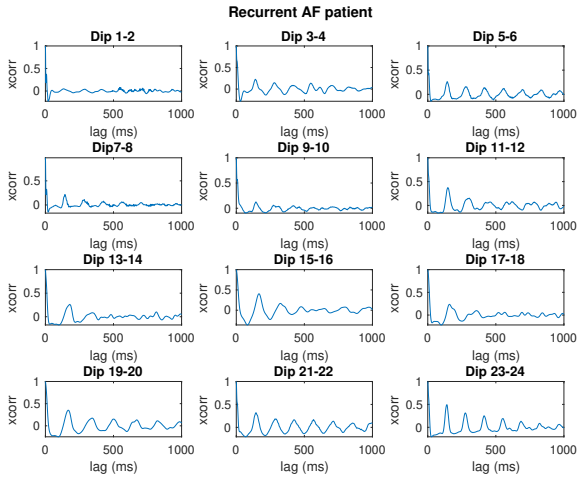

Figure 4. Autocorrelation of 12 dipoles located in the LA and the RA from a patient with recurrent AF .

4. Conclusions

In order to estimate the spatial organisation of activation during AF that is directly related to the underlying pathophysiological mechanisms responsible for AF, we describe the relative organisation in terms of the similarity of activation sequences measured along the right atrium undergoing an ablation procedure. We found that during AF, the autocorrelation in activation sequences is a monotonically decreasing exponential unction depending on the organisation of these activations with different distance to the first relative maximum. Activation sequences recorded from closely spaced electrodes would be expected to be similar, however the variation of the functions depends on the spatial organisation and is also dependent on the atrial region.

Given the observed relationship between the autocorre-

lation of the activation sequences and the periodicity of the signals and also their temporal distribution, it should be noted that the calculation of the decay constant of the decaying exponential allows to assess the degree of temporal and spatial organisation of the activation sequences during AF and by means of a single metric. It should be noted that this method can be complementary to the previously mentioned spatial correlation parameter [15], giving additional and complementary information on the evolution of the waves throughout the atrial space. On the other hand, a shorter length of the activation sequences would allow a finer temporal evolution to be evaluated, however the chosen length, supported by previous studies [15], allows averaging of transients found in the signal.

In summary, greater similarity in the voltage of successive electrograms and lower frequency of electrical signals recorded at high RA and coronary senus ostium may be associated with a greater likelihood of achieving reversion to sinus rhythm and a lower likelihood of recurrences. Nevertheless, a larger study is needed to draw conclusions.

Acknowledgements

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