Analysis of Electrogram Complexity during Atrial Fibrillation for Ablation duration Assessment

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Abstract

The aim of this study was to assess the reliability of the complexity analysis of single electrogram as an estimator of the length of the ablation procedure necessary for AF termination.

Left and right atrial endocardial bipolar electrograms were recorded during ablation procedure of AF in 27 patients. Up to 30 second electrogram samples were measured at baseline, after each stage of ablation (LPV, roof, CFAE etc.) and prior to termination. For each electrogram, algorithmic complexity was calculated.

Electrograms had significantly lower algorithmic complexity for patients who had two or less ablation stages performed than for patients for whom more than two ablation stage was performed ($p < 0.001$). ROC analysis showed 100% statistical sensitivity for 81% statistical specificity.

These results show that algorithmic complexity increases with a number of ablation stages needed to terminate AF, which is related with the duration of the ablation procedure.

1. Introduction

Atrial Fibrillation (AF) is the most complex and common sustained arrhythmia [1]. It is one of the main causes of hospitalization, while mechanisms that sustain AF are still not understood [2,3,4]. Haïssaguerre et al. [5] observed that electrical activity originating from the pulmonary veins may trigger AF, establishing the pulmonary vein area as a main target for isolation during ablation therapy of Atrial Fibrillation. The isolation of Pulmonary Veins during ablation procedure not always leads to termination of Atrial Fibrillation, and ablation of additional sites is necessary, which complicates and lengthens the ablation procedure to an unknown extent.

Another target for the ablation procedure is sought in the areas with complex atrial electrograms, and for that purpose many algorithms to measure or quantify signal complexity were developed [6]. However, rarely those studies address the measurement of electrogram complexity in a fixed location as a measure useful during ablation procedure.

The aim of this study was to assess the reliability of the complexity analysis of single electrogram as an estimator of the length of the ablation procedure necessary for AF termination.

2. Methods

2.1. Study population

Left and right endocardial atrial bipolar electrograms were recorded during ablation procedure of AF in 27 patients at the mean age of 62 ± 9 years. AF was paroxysmal in 12, persistent in 12 and permanent in 3 patients. 30 seconds electrograms were measured with the sample rate 1 kHz at baseline, after each stage of ablation (LPV, RPV, roof, fossa, CFAE etc.) and prior to termination. The total numbers of patients with particular numbers of ablation stages are shown in Table 1.

Table 1. The total number of patients with particular number of ablation stages performed to terminate Atrial Fibrillation.

Number of ablation stages	Number of patients
0	4
1	11
2	6
3	3
4	1
5	0
6	2

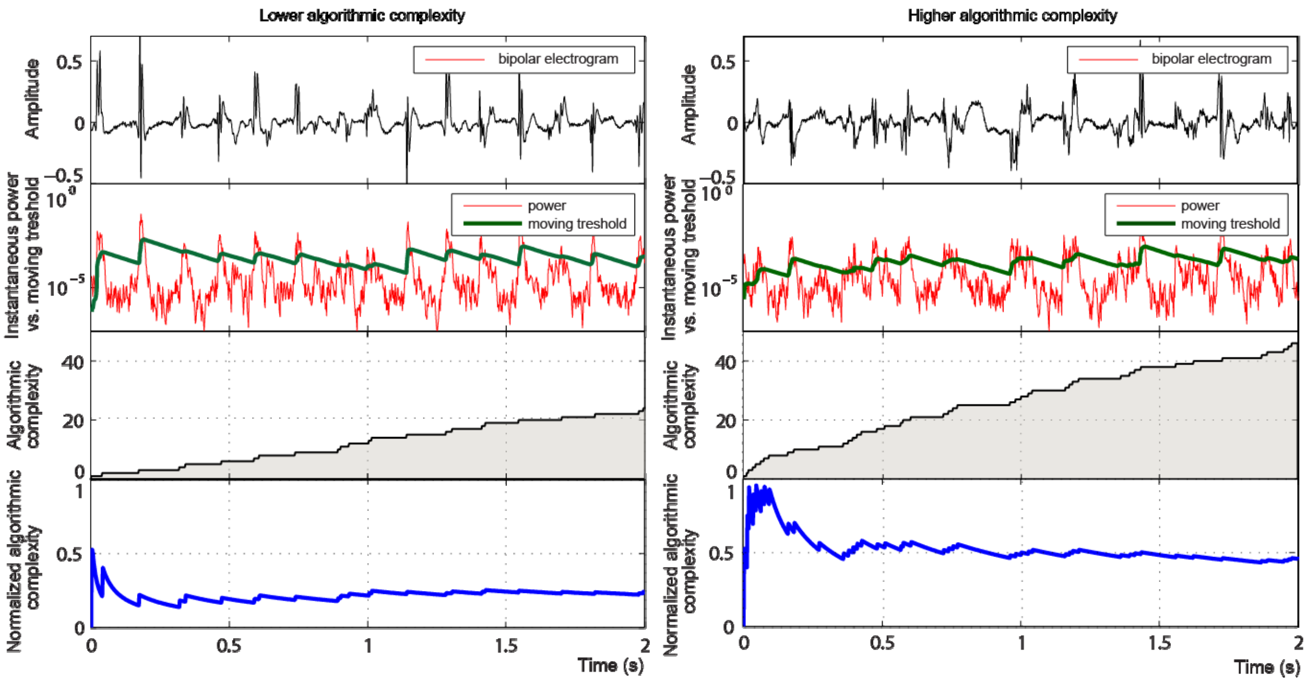

Figure 1. Comparison of two electrograms with different algorithmic complexity. A 2 s window example is presented. In the top figure, atrial electrograms measured at Coronary Sinus are presented. In the second image row, instantaneous power [7] of the electrogram is compared to the threshold (logarithmic y-scale was used). Latter image rows show algorithmic complexity and normalized algorithmic complexity for both cases.

The study group was divided into two groups, based on the number of ablation stages. The division process is explained in the Section 2.3 Statistical analysis.

For each patient, algorithmic complexity was calculated for 2, 5 and 10 s electrogram fragments, gathered in Coronary Sinus (CS) before the ablation.

2.2. Algorithmic complexity calculation

In this study a method introduced by Pitschner and Berkowitsch [7] was used. Based on symbolic dynamics, it calculates algorithmic complexity of intracardiac measurements of electrical activity of the heart atria.

Complexity of the string of characters may be defined as the length of its shortest possible description in some universal language. In order to calculate it, measured signals were transformed into binary strings based on the moving threshold criteria. The moving threshold is defined as:

$$A_i = MP_i + 0.1V_i$$

with MP_i defined as mean instantaneous power and V defined as adaptive power variance for every sample i [7]. Both quantities are calculated using adaptive filters. Using instantaneous signal power P_i and moving threshold A_i it was possible to define the translation rule from the electrogram to the binary string:

$$S_i = \begin{cases} 1; & P_i > A_i \\ 0; & P_i \leq A_i \end{cases}$$

Algorithmic complexity for obtained binary string was calculated by Lempel-Ziv algorithm [8]. For each element of the string, a check is performed, if the examined sequence of characters has appeared already in the signal. If not, algorithmic complexity raises by 1 and the sequence is remembered. Otherwise, we should add another sample and check again whether the sequence occurred.

For example, the sequence S1=110010100111 of the length n=12 can be split into 5 different sequences: (1)(10)(01)(0100)(111), providing algorithmic complexity C_{12}=5. In contrast, the simple sequence S2=101010101010 of the same length should be transformed into words as (1)(0)(1010101010), which gives the result of C_{12}=3.

For all electrograms algorithmic complexity was calculated for 2, 5 and 10 second electrogram fragments (single-window). Additionally, the results were accompanied by mean and median value of algorithmic complexity in full 30 s recording, estimated in a moving window. Figure 1 illustrates the differences between two electrograms of different complexity, comparing particular steps of the method. For both signals normalized algorithmic complexity rapidly grows in the beginning, but for more complex signal fluctuates constantly around the maximum value, whereas for less complicated it decreases significantly.

2.3. Statistical analysis

The statistical significance of the results was tested using ANOVA tests, ROC curve, sensitivity and specificity and Wilcoxon signed-rank test.

ANOVA test was used to check whether the complexity for the baseline electrogram is dependent on the number of ablation stages. For this purpose, all patients were twice separated into two groups:

- with the distribution factor 1 (which means that in the first group were patients with the number of ablation stages not lower than one, and in the second group were those with more than one ablation stage);
- with the distribution factor 2 (by analogy).

In all cases, a statistical significance (p) lower than 0.05 was considered as significant.

To check if the distribution factors were chosen correctly sensitivity and specificity was calculated for each case, and ROC analysis was performed.

Wilcoxon signed-rank test can be performed when comparing two repeated measurements. In this study it was used to examine differences between the complexity of the signals measured at the baseline and just before termination of fibrillation for each patient.

3. Results

Electrograms had significantly lower algorithmic complexity for patients who underwent no more than one ablation stage, than for patients for whom more than one ablation stage was performed ($p < 0.001$ for ANOVA tests). The same result has been obtained for the second distribution factor. Irrespectively of the window size and use of single window or sliding window on 30s sample, p-values have been significantly lower than 0.05 for every window length (Table 2).

Algorithmic complexity value in all groups for the single, 5s window measurement is depicted in Fig.2&3.

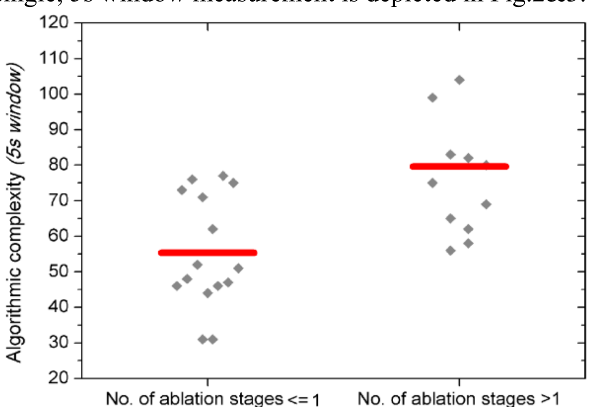

Figure 2. Algorithmic complexity of electrogram measured before ablation procedure at CS for patients who underwent no more than one ablation stage, and also for those who underwent more than one ablation stage.

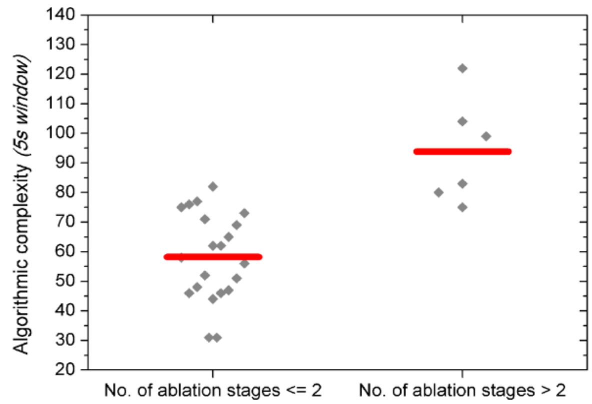

Figure 3. Algorithmic complexity of electrogram measured before ablation procedure at CS for patients who underwent no more than two ablation stages and for patients for whom more than two ablation stages was performed.

Table 2. p-values obtained from ANOVA test for algorithmic complexity of electrograms measured before ablation procedure at CS, of or different window lengths.

window	30s average	30s median	single-window
2 s	0,004	0,0004	0,0155
5 s	0,0003	0,0004	0,0017
10 s	0,0005	0,0004	0,0008
2 s, 5 s, 10 s		< 0.0001	

Results of Receiver-Operating Characteristic (ROC) are presented in Fig. 4. Sensitivity, specificity and accuracy values for the analyzed indices for the 100% sensitivity are shown in Table 3. The area under the ROC curve for both methods and each test window is above 70 %. The best result was obtained for the electrograms with a length of 10 s.

No significant differences were found between the algorithmic complexity of signals measured at the baseline and preterm for each patient (p=0.28 in Wilcoxon signed-rank test).

Table 3. Specificity and accuracy obtained for the 100% sensitivity for the separation into two groups based on algorithmic complexity; also area-under ROC (AUC).

window	Sensitivity	Specificity	Accuracy	AUC
	No. of ablation stages ≤ 1 vs. > 1			
2 s	100%	20%	56%	0,74
5 s	100%	60%	78%	0,83
10 s	100%	67%	81%	0,85
	No. of ablation stages ≤ 2 vs. > 2			
2 s	100%	52%	63%	0,89
5 s	100%	81%	85%	0,97
10 s	100%	90%	93%	0,99

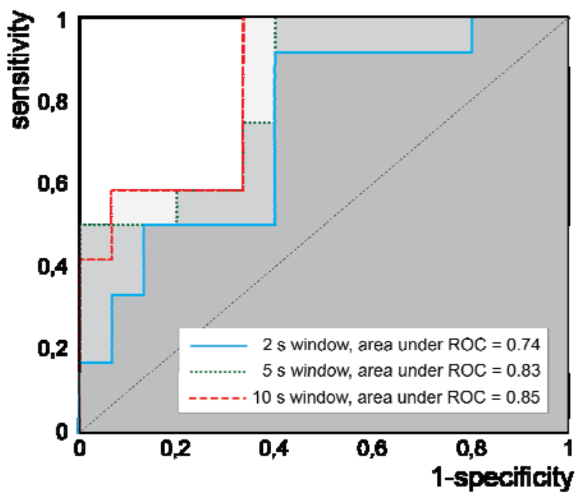

Figure 4. ROC analysis of classification performance of division into groups of patients who underwent no more than 1 ablation stage and for whom more than 1 ablation stage was performed, for algorithmic complexity analysis.

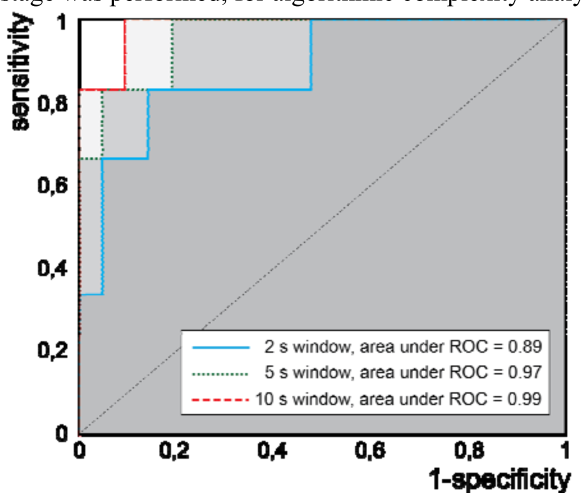

Figure 5. ROC analysis of classification performance of division into groups of patients who underwent no more than 2 ablation stages and for whom more than 2 ablation stages was performed, for algorithmic complexity analysis.

4. Discussion

In the study group, a significant difference was found between patients that needed 1 or 2 ablation stages in comparison with those who needed more. However, the study groups were rather small and further study in larger groups is needed (one with only 6 patients, see Fig.3).

The Coronary Sinus location was chosen as a common location for catheter placement during ablation therapy. This, combined with a short recording required for calculating algorithmic complexity (< 10s), renders this method helpful in ablation duration assessment.

5. Conclusions

In our study algorithmic complexity of electrograms measured at coronary sinus prior to ablation procedure were significantly lower for patients, for whom 1 or 2 ablation stages were needed in comparison to patients for whom more ablation stages were necessary for AF termination ($p < 0.001$).

No significant differences were found between the algorithmic complexity of electrograms measured in Coronary Sinus prior to ablation and just before termination and preterm for each patient.

Acknowledgements

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