Functional Data Analysis for ECG Recordings of Paroxysmal Atrial Fibrillation Patients Before and After Pulmonary Vein Isolation

Nuria Ortigosa[1], Guillermo Ayala[2], Óscar Cano[3]

[1] I.U. Matemática Pura y Aplicada, Universitat Politècnica de València, Spain
[2] Department of Statistics and Operations Research, Universitat de València, Spain
[3] Servicio de Cardiología, Hospital Universitari i Politècnic La Fe. Valencia, Spain

Abstract

Pulmonary vein isolation is the cornestone of current ablation techniques for patients with paroxysmal atrial fibrillation in order avoid recurrences of the arrhythmia and maintain sinus rhythm. This study aimed to analyse the existence of significant variations in surface ECG after pulmonary vein isolation by means of functional data analysis. 12 consecutive unselected patients suffering from paroxysmal atrial fibrillation who underwent catheter ablation were included in the study. Each patient was monitored in sinus rhythm before and after catheter ablation. P-waves of bipolar lead II were delineated. Functional data were fitted from these segments and the first and second derivatives evaluated using them. Maximum first and second derivatives of the curves corresponding to P-waves resulted to decrease significantly when pulmonary veins were isolated (from 16.59±5.11 and 0.66±0.28 to 13.41±4.71 and 0.52±0.31, respectively). The use of these features could potentially help to identify the disconnection of pulmonary veins in a non invasive way.

1. Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia in clinical practice [1, 2]. This arrhythmia is characterized by desynchronization of atria and ventricles, which causes a fast and irregular heart rhythm and disorganized propagation of electrical signals through the atria.

AF treatment includes antiarrhythmic drugs and non-pharmacological therapies, such as electric isolation of the pulmonary veins using catheter ablation. The efficacy of these treatments depends on the clinical classification of the arrhythmia [3]. Regarding catheter ablation, it is able to obtain about 80% of success of freedom from arrhythmia for paroxysmal AF patients (those who present self-terminating episodes, usually within 7 days) [1].

In the last years, since early pulmonary vein reconnection is a predictor of late arrhythmia recurrence after a single ablation procedure [4, 5], pulmonary vein isolation has been studied in many works in order to analyse its anatomical basis [6], and the most suitable predictors in order to select the right candidates for catheter ablation [7, 8].

In this paper we have studied the surface electrocardiogram variations before and after catheter ablation. These differences are analysed by means of functional data analysis with the objective of identifying markers for the disconnection of pulmonary veins.

2. Materials

The study consisted of 12 consecutive unselected patients who suffered from paroxysmal atrial fibrillation and who underwent catheter ablation in a specific arrhythmia clinic of a tertiary centre.

The surface ECG was simultaneously recorded with the intracavitary electrogram recordings starting before and during all the ablation process, so that each subject was constantly monitored and segments in sinus rhythm were obtained before and after catheter ablation.

3. Methods

3.1. Signal preprocessing

The ECG signal is first filtered in order to remove baseline wander (by means of cubic splines [9]). Then, powerline interference is removed using a Notch filter at 50Hz.

After that, P-waves of lead II are carefully delineated for each one-minute length segment before catheter ablation begins and after it has ended and the pulmonary veins have been successfully isolated.

3.2. Functional data analysis

Functional data analysis are the techniques which analyse and provide information about samples of curves and other functional observations [10, 11]. Thus, these tech-

 ISSN: 2325-887X DOI: 10.22489/CinC.2018.306

niques represent data recorded at discrete times as a continuous function $f(t)$ to work with.

Assuming that data are smooth, $f(t)$ can be constructed using a set of K basis functions ϕ_k as a linear combination of these basis functions:

$$f(t) = \sum_{k=1}^{K} c_k \phi_k(t) \quad (1)$$

where c_k are the coefficients of the expansion.

In our case, we have used splines as basis functions, since spline bases are more flexible than other basis functions. Splines are piecewise polynomials defined by the number of knots and the order. At internal breakpoints the polynomials are required to be continuous (this is, the derivatives match up to the order $m - 2$, where m is the degree of the polynomial).

In this study we have used B-splines of order 4, and we have analysed the first and second derivatives of the functions fitted to P-waves before and after catheter ablation, in order to look for significant differences and variations. These derivatives are defined in Equations 2 and 3, respectively.

$$Df(t) = \frac{d}{dt} f(t) \quad (2)$$

$$D^2 f(t) = \frac{d^2}{dt^2} f(t) \quad (3)$$

4. Results

Once P-waves were delineated in lead II, functional data analysis was performed over these segments before and after catheter ablation. Then, first and second derivatives were calculated.

Table 1 shows average values and standard deviations for the maximum and minimum first and second derivatives, whereas Figure 1 shows the boxplots of these features.

Table 2 shows the statistical analysis with p-values of the Wilcoxon rank sum test indicating statistically significant differences between the two sets of data (before and after pulmonary vein isolation).

We can observe that both maximum values for first and second derivatives decrease after catheter ablation has successfully ended, whereas the minimum values for first and second derivatives also decrease (in absolute value) with respect to the beginning of the ablation procedure.

However, only the maximum value for the first derivative and the minimum value for the second derivative have resulted to be statistically significant according to results shown in Table 2.

Table 1. Results for the 12 subjects included in the study, differentiating among features extracted from the P-wave before and after catheter ablation. * indicates significant differences.

Feature	Before	After
Minimum first derivative	-18.79±9.54	-16.94±8.32
Maximum first derivative	16.59±5.11	13.41±4.71*
Minimum second derivative	-1.12±0.47	-0.89±0.49*
Maximum second derivative	0.66±0.28	0.52±0.31

Table 2. Wilcoxon rank sum test p-values for the different features shown in Table 1. Boldface indicates significant differences.

Feature	p-value
Minimum first derivative	0.680
Maximum first derivative	**0.001**
Minimum second derivative	**0.029**
Maximum second derivative	0.094

These results may be related to the less fragmentation and variability present in patients without atrial fibrillation, or in those patients for whom catheter ablation has obtained successful results and sinus rhythm is maintained.

More detailed studies should be done, but the presented features obtained by means of functional data analysis may open a door for helping clinicians in the follow-up of patients who have undergone catheter ablation when looking for possible recurrences of the arrhythmia. The use use of a non-invasive technique such as the ECG in the identification of recurrences would be of great help to use the most suitable treatment before the first symptoms of the arrhythmia appear again.

5. Conclusions

In this paper we have presented a study whose aim is to analyse the differences in the surface ECG before and after catheter ablation in patients who suffer atrial fibrillation. Once P-waves of lead II have been delineated, functional data analysis using splines as basis functions has been performed, and first and second derivatives of the fitted functions have shown to be significantly smaller once catheter ablation has completely ended.

Future work will focus on enlarge the population study, analyse other functional features of interest and consider possible trends in the results, for those cases of possible recurrences of the arrhythmia and those who maintain the sinus rhythm.

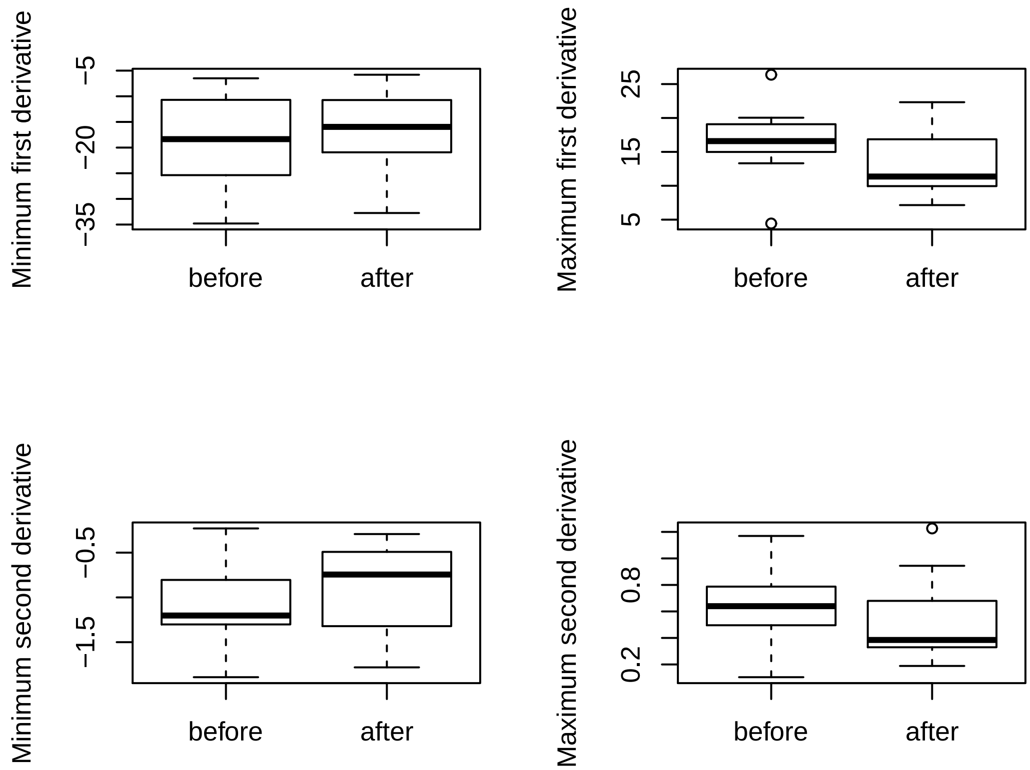

Figure 1. Boxplot of features extracted before and after catheter ablation.

Acknowledgements

N. Ortigosa acknowledges the support from Generalitat Valenciana under grant Prometeo/2017/102, from Spanish MINECO under grant MTM2016-76647-P, from Universitat Politècnica de València under grant 20170373, and from VLC-BIOMED 2017 (Universitat de València and Hospital La Fe / IIS La Fe) under grant 10-ARVEAP-GALBIS-CANO-2017-A.

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Address for correspondence:

Nuria Ortigosa
I.U. Matemática Pura y Aplicada,
Universitat Politècnica de València
Camino de Vera s/n, Edif. 8E, acceso F.
46022 Valencia (Spain)
nuorar@upvnet.upv.es