P-wave Analysis in Paroxysmal Atrial Fibrillation Patients before and after Pulmonary Vein Isolation

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Abstract

This study aimed to assess common markers obtained from the surface ECG in order to analyze if they present significant variations after pulmonary vein isolation in patients with atrial fibrillation.

12 consecutive unselected patients suffering from paroxysmal atrial fibrillation who undergone catheter ablation were included in the study. The surface ECG and intracavitary electrocardiogram recordings were simultaneously acquired previously and during all the ablation process. Several markers were studied for the P-waves from V1 lead before and after the procedure, such as their average amplitude, duration, kurtosis, skewness, and amplitude or duration dispersion.

P-wave duration as well as the amplitude dispersion index and kurtosis feature resulted to be significantly smaller when pulmonary veins were isolated. The use of these features allows to identify the disconnection of pulmonary veins in 91% of patients. This analysis would open a door for non-invasive identification of spontaneous reconnection of pulmonary veins, which is a major cause of recurrence of atrial fibrillation.

1. Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia [1, 2] in clinical practice. AF is characterized by rapid, disorganized propagation of electrical signals through the atria. Thus, the atria and ventricles do not beat in a coordinate way, creating a fast and irregular heart rhythm.

AF treatment includes antiarrhythmic drugs and non-pharmacological therapies, such as electric isolation of the pulmonary veins using catheter ablation. The efficacy of treatments depends on the clinical classification of the arrhythmia [3]. In particular, catheter ablation 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].

Recently, pulmonary vein isolation has been studied in many works, since early pulmonary vein reconnection is a predictor of late arrhythmia recurrence after a single ablation procedure [4, 5]. For example, the anatomical basis of pulmonary vein reconnection after ablation has been studied by McGarry and Narayan in [6] whereas Epicoco and Sorgente [7] and Balk et al. [8] have analysed the importance of using predictors to select the right candidates for catheter and radiofrequency catheter ablation in order to avoid recurrences, respectively.

Due to the importance of identify predictors of reconnection of pulmonary veins, in this paper we propose different markers of the surface ECG in order to confirm the isolation of pulmonary veins after a catheter ablation procedure.

2. Materials

12 consecutive unselected patients suffering from paroxysmal atrial fibrillation who undergone catheter ablation in a specific arrhythmia clinic of a tertiary centre were included in the study. The 12-lead surface ECG and intracavitary electrocardiogram recordings were simultaneously acquired previously and during all the ablation process. Thus, each patient was constantly monitored and recordings in sinus rhythm before and after catheter ablation (once all the pulmonary veins were isolated) were obtained.

3. Methods

3.1. Signal preprocessing

First, the ECG signal is filtered in order to remove baseline wander (by means of cubic splines [9]). Also, power-line interference is removed using a Notch filter at 50Hz.

Then, P-waves are carefully delineated and one-minute length segment is extracted before catheter ablation begins, and another one-minute length is also analysed once the procedure has ended, and the four pulmonary veins have been disconnected.

 ISSN: 2325-887X DOI:10.22489/CinC.2017.284-091

3.2. Feature extraction

Once P-waves have been delineated in V1 lead, several features were calculated, such as the average amplitude and the duration of the P-waves.

Other features studied about P-waves morphology were kurtosis and skewness. Kurtosis is a measure of how outlier-prone a distribution is. It is defined as

$$kurtosis = \frac{\sum_{i=1}^{N}(x_i - \mu)^4/N}{\sigma^4} \quad (1)$$

where μ is the mean, σ is the standard deviation, and N is the number of samples.

The kurtosis for a standard normal distribution is 3, so as distributions which are more outlier-prone than the normal distribution have kurtosis values greater than 3, whereas those distributions less outlier-prone have kurtosis smaller than 3.

Skewness is a measure of the asymmetry of the data around the mean. If it is negative, the data are spread out more to the left of the mean than to he right, and vice versa if it is positive. It is defined as

$$skewness = \frac{\sum_{i=1}^{N}(x_i - \mu)^3/N}{\sigma^3} \quad (2)$$

The skewness for a standard normal distribution is zero, and any nearly symmetric data should have a skewness near zero. If it is negative, the data are skewed left whereas positive values indicate that data are skewed right.

In addition, other measures of dispersion have also been calculated. Amplitude dispersion index (ADI) measures the variability of the amplitude of P-waves along the recording. It is defined as

$$ADI_i = \frac{\max_i\{\max\{Ampl_j\} - \min\{Ampl_j\}\}}{\max_{i,j}\{Ampl\}} \quad (3)$$

where $Ampl_j$ refers to amplitude of the j^{th} P-wave of subject i^{th}.

Dispersion of P-wave duration was also studied. It is defined as the difference between the maximum and the minimum duration of the P-waves of the i_{th} patient:

$$Dispersion_i = \max_i\{dur_{P-wave}\} - \min_i\{dur_{P-wave}\} \quad (4)$$

where dur refers to the duration of the P-wave .

Once the features have been extracted, the Wilcoxon signed-rank test was performed between the two sets of data (before and after pulmonary vein disconnection).

4. Results

As above-said, our dataset consisted of 12 ECGs of patients with AF episodes who undergone catheter ablation. Several features have been analysed from the ECG recordings before and after catheter ablation.

Table 1 shows median values and interquartile ranges for the different features extracted (also shown in Figure 1), and Table 2 shows the statistical analysis with p-values of the Wilcoxon unsigned rank sum test indicating statistical significance.

We can observe that the average amplitude of P-waves does not provide enough information for discrimination, as well as the asymmetry morphology measurement (skewness).

On another hand, duration of P waves was found to be significantly longer before catheter ablation. This is in line with prior results presented by Shrestha et al in [10], where they observe that there was a significant reduction of the negative deflection of P-wave in V1 as well as an increment of the duration of the positive component of the P-wave.

In addition, a measure of how outlier-prone is a distribution (kurtosis) was also significantly smaller once catheter ablation procedure has ended. In fact, this find is also related to the fact that the amplitude dispersion index (ADI) is also smaller once the pulmonary veins have been isolated during the ablation procedure. Indeed, these differences are highly statistically significant (see Table 2), and just using this feature we can differentiate the recordings with 91% and 83% of accuracy, respectively. A comparison to observe the differences of P-waves before and after catheter ablation is depicted in Figure 2, where a reduction of the amplitude dispersion after the procedure is shown.

These results agree with the study reported in [11], where recordings of a group of patients with persistent atrial fibrillation who were in sinus rhythm were compared to ECG recordings of a normal control group. Controls were characterized by less fragmentation and variability, respect to AF patients. This may be explained by the disorganized atrial activity in patients who suffer atrial fibrillation. In contrast, in [11] the control group resulted to be characterized by shorter P-wave duration. More studies will be necessary to study the variations of this feature.

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
Mean amplitude	784 (582-928)	845 (518-917)
Duration	140 (115-162)	126 (103-151) *
Kurtosis	1.73 (1.69-1.79)	1.63 (1.59-1.68)*
Skewness	0.25 (0.01-0.33)	0.18 (0.05-0.22)
ADI	0.58 (0.45-0.67)	0.50 (0.31-0.55)*
Dispersion	46 (32-59)	45 (32-62)

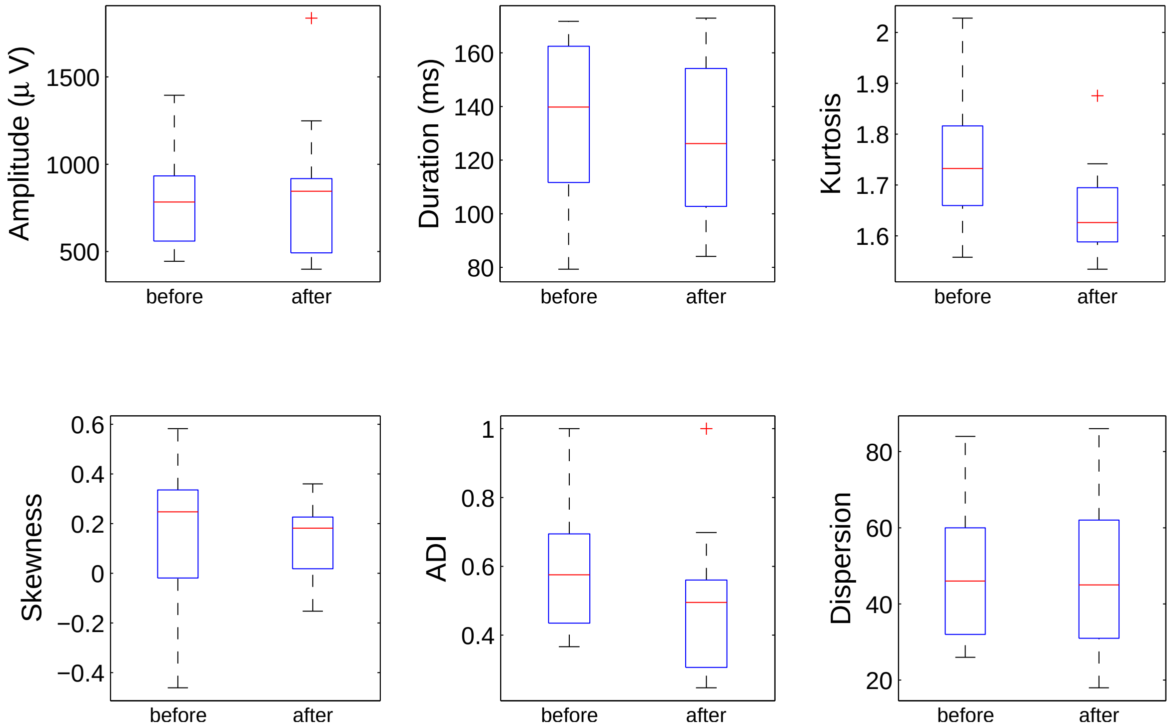

Figure 1. Boxplot of features extracted before and after catheter ablation.

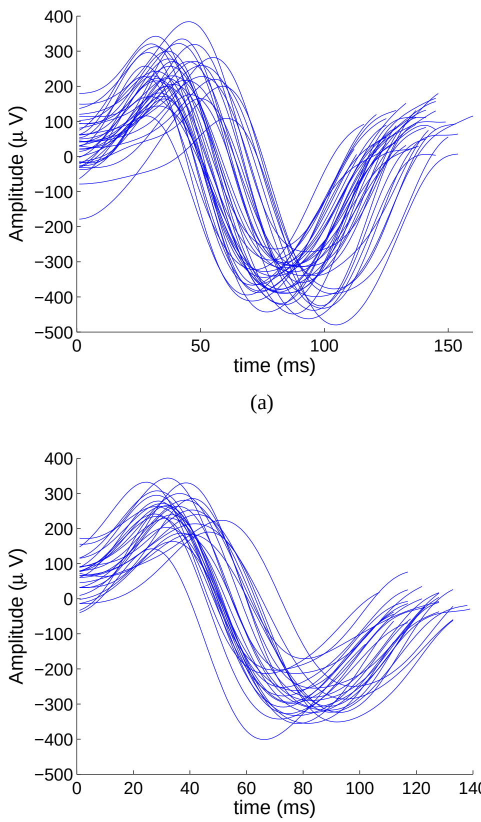

Figure 2. P-waves extracted from one patient (a) before and (b) after catheter ablation.

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

Feature	p-value
Mean amplitude	0.8501
Duration	**0.0342**
Kurtosis	**0.0010**
Skewness	0.3394
ADI	**0.0093**
Dispersion	0.5554

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. It has been shown that duration of P-waves, amplitude dispersion index and kurtosis feature significantly become smaller after catheter ablation, once the pulmonary veins have been isolated.

Future work will focus on enlarge the population study, analyse other morphological 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.

Acknowledgements

This work was supported by Spanish Ministry of Economy and Competitiveness (MINECO) under grants MTM2013-43540-P and MTM2016-76647-P.

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