Pulmonary Vein Isolation Induces Changes in Vectorcardiogram P-wave Loops

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Abstract

Pulmonary vein isolation (PVI) is considered a standard treatment of paroxysmal atrial fibrillation aiming to restore and maintain sinus rhythm. The purpose of this study is to analyse how the PVI treatment affects the electrical conduction pattern in the atria. We have compared the morphology of P wave loops extracted from the vectorcardiogram (VCG) before and after PVI.

Ten patients suffering from paroxysmal atrial fibrillation who underwent PVI were included in the study. All patients were in sinus rhythm before as well as after the procedure. Vectorcardiogram was obtained using the Kors matrix and the resulting P-waves were automatically delineated. Using these marks, P-wave loops were constructed from the three orthogonal leads of the VCG. The first and second eigenvalues of the P-wave loops increased after the PVI procedure was completed, whereas the ratio of the second to the first eigenvalue, quantifying the roundness of the P-wave loop, decreased significantly after PVI. These results show that PVI induces morphological changes of the P-wave loops.

1. Introduction

Atrial fibrillation (AF) is a cardiac arrhythmia characterized by a fast and irregular heart rhythm, caused by irregular beat of the atria, which are desynchronized with the ventricles [1]. Atrial fibrillation is the most common arrhythmia in clinical practice, affecting 14-17 million patients in the European Union by 2030 [2].

Rate control or rhythm therapy control by antiarrhythmic drugs are the preferred methods to maintain sinus rhythm in AF patients [2]. Nevertheless, guidelines also suggest that AF may be treated by catheter ablation within or around the pulmonary veins [3].

Pulmonary vein isolation (PVI) success rates, defined as freedom from AF without antiarrhythmic therapy, are about 80% for paroxysmal AF subjects [4], however, there is a progressive and significant decline in these rates at long term follow-up [5]. Thus, the cornerstone of successful AF ablation has been the durable PVI [6] and it is therefore desirable to study changes induced by the procedure that may be linked to durability of the PVI.

Previous studies have analysed how PVI changes the surface ECG signal by decreasing the P-wave duration [7, 8], and P-wave amplitude and duration dispersion [9–11].

In this study we propose to analyse the vectorcardiogram (VCG) to assess how PVI affects the electrical conduction pattern in the atria. Based on the 12-lead surface ECG of patients with paroxysmal AF in sinus rhythm, we have extracted the VCG, and then compared the morphology of P-wave loops before and after PVI to reveal changes induced by the procedure.

2. Materials

The cohort under study consisted of 10 patients suffering from paroxysmal AF who were referred to the arrhythmia clinic of Hospital Universitari i Politècnic La Fe in Valencia (Spain) for PVI. Average age for the patients included in the study was 49$\pm$7 years, 90% were men, and 1 patient had other cardiomyopathies. Approval was obtained from the La Fe Health Research Institute ethics committee.

Standard 12-lead ECG were acquired immediately before and half an hour after the procedure, respectively. For each patient, one 60-second ECG segment before and one 60-second ECG segment after PVI were extracted for analysis. All patients were in sinus rhythm, i.e. with visible P-waves in the extracted ECG segments.

3. Methods

3.1. Signal preprocessing

The ECG recordings were first pre-processed in order to remove noise and interferences. A notch filter was applied to remove powerline interference at 50Hz, and cubic spline interpolation [12] were used to remove baseline wander. Vectorcardiograms (VCG) were obtained by transforming the ECGs using the Kors matrix [13], thus resulting in the

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three orthogonal Frank leads.

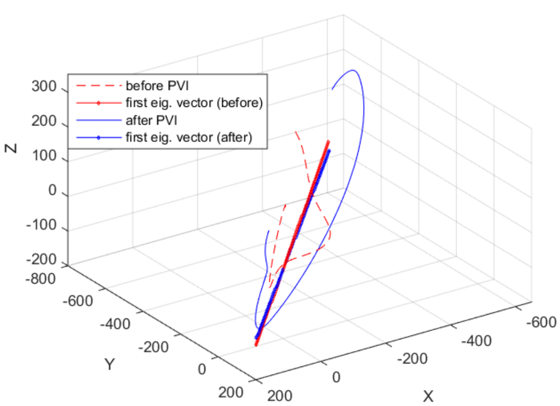
The P-waves onset and offset were automatically delineated from the VCG, and the annotations were manually revised. Only P-waves of sufficient signal quality were considered for further analysis; P-waves with a cross-correlation below 0.9 to the average P-wave in the recording were excluded.

3.2. Vectorcardiogram loop analysis

P-wave loops were constructed using the orthogonal VCG lead and, for each loop, the three associated eigenvectors were extracted by applying singular value decomposition. The eigenvalues are denoted λ_i, where $i = 1, 2, 3$, and $\lambda_1 > \lambda_2 > \lambda_3$.

Each eigenvalue is associated to its respective eigenvector, and represents the energy in the corresponding dimension. Hence, the first eigenvalue λ_1 represents the magnitude of the loop in the direction of the maximum variation. Examples of P-wave loops and their corresponding eigenvectors associated with λ_1 are displayed in Fig. 1.

The first and second eigenvalues (λ_1, λ_2) were analysed in this study, as well as the ratio of the second to the first eigenvalues ($\rho = \lambda_2/\lambda_1$). This ratio ρ quantifies the roundness of the P-wave loop, i.e. it describes the shape of the loop, and how the morphology is distributed along the two diagonals.



(a)

Figure 1. P-wave loop obtained from a patient before (red) and after PVI (blue), and the corresponding eigenvector associated with λ_1.

4. Results

Following exclusion of P-wave segments with insufficient signal quality, VCG loops could be constructed from 69% of the P-waves before and and 75% of the P-waves after PVI, respectively. Figure 2 depicts the P-wave loops obtained from a patient before (2a) and after (2b) PVI, respectively. Note that the P-wave loop morphology exhibits limited variation within each phase, but changes after the PVI, cf. (2c).

These P-wave morphology variations and changes in response to PVI are also reflected in the extracted features λ_1, λ_2 and ρ, see Fig. 3.

For each patient, averages $\bar{\lambda}_1, \bar{\lambda}_2$ and $\bar{\rho}$, based on P-wave loops before and after PVI, respectively, were computed. Table 1 shows population average and standard deviations of $\bar{\lambda}_1, \bar{\lambda}_2$ and $\bar{\rho}$ before and after PVI.

Table 1. Results obtained for the 10 patients included in the study. Features are compared before and after PVI. Student's t-test p-value is also included, * indicates significant differences.

Feature	Before	After	p-value
$\bar{\lambda}_1$	5800±3000	7600±3200	0.0023*
$\bar{\lambda}_2$	1700±500	1900±700	0.3241
$\bar{\rho}$	0.35±0.19	0.30±0.20	0.0378*

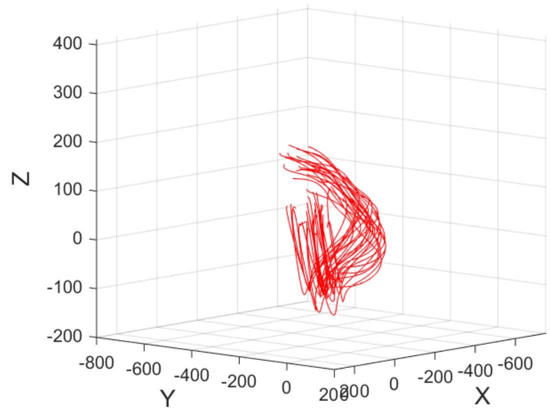
Results show that $\bar{\lambda}_1$ and $\bar{\lambda}_2$ increase after PVI, and a paired Student's t-test indicates that the change in $\bar{\lambda}_1$ is significant. This behaviour corresponds to an increment of both diagonals of P-wave loops, especially for the large diagonal. Further, results show that $\bar{\rho}$ decrease significantly after PVI indicating that the P-wave loops are less round.

5. Conclusions

The aim of the present study was to analyse morphology differences in P-wave loops of obtained from patients with paroxysmal AF before and after PVI.

Analysis of the first and second eigenvalues as well as the measurement of the loop roundness have shown that PVI induces morphological changes. Loops are significantly less round, more ellipsoidal after PVI. These results indicate that catheter ablation procedure modifies the electrical propagation pattern in the atria, and that this changes can be visualized in the VCG.

Future work will focus on enlarging the cohort under study, analyse other VCG features, and investigate possible links between VCG features and arrhythmia recurrences.



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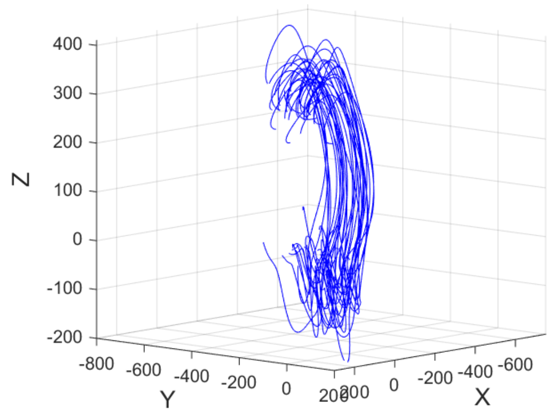

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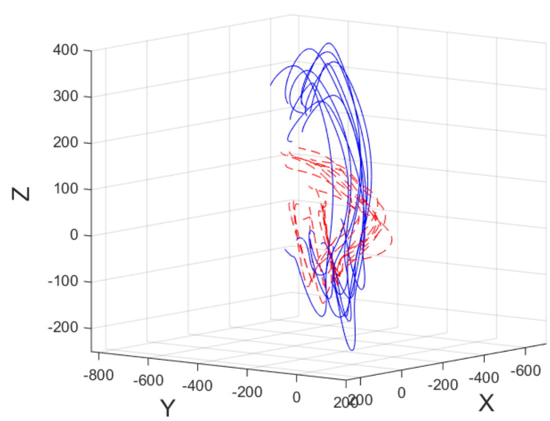
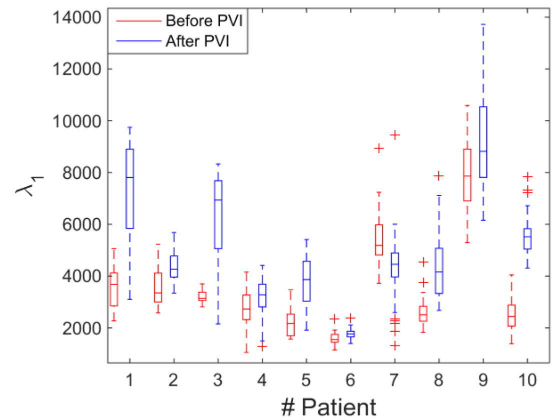


(c)

Figure 2. Example of P-wave loops of a patient included in the study. (a) before PVI, (b) after PVI, (c) detail of the first 10 loops before (red, dot line) and after PVI (blue solid line).



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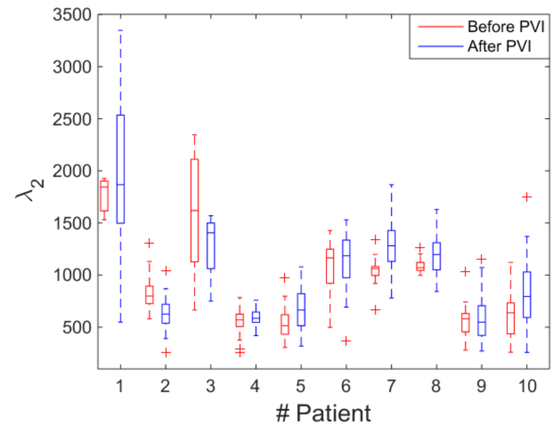

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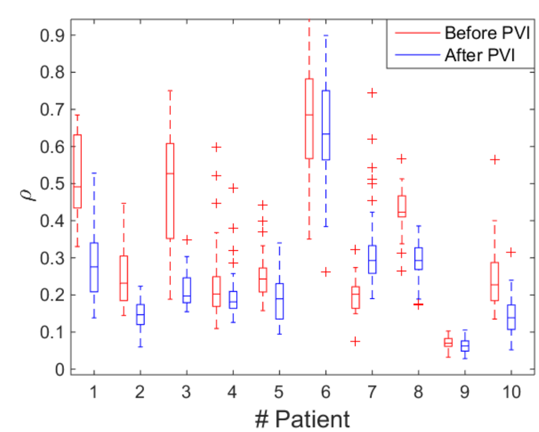

(c)

Figure 3. Boxplots for the different features under analysis of all patients included in the study. (a) λ_1, (b) λ_2, (c) ρ.

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