Poincaré Plots of Time-Frequency Parameters Applied to the Prediction of Atrial Fibrillation Termination

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Abstract

Atrial Fibrillation (AF) episodes are commonly encountered in the daily clinical practice and cardiologists have often to face the difficulty of classifying between terminating and non-terminating AF episodes. Given that in these critical situations a decision must be made with the utmost urgency, it would be desirable to have a visualization tool of easy interpretation that could provide a fast and reliable prediction of AF episode evolution. In this essay, a method based on Poincaré plots and time-frequency analysis is presented as a new technique of AF diagnosis.

1. Introduction

Atrial fibrillation (AF) is the most frequently observed arrhythmia in routine clinical practice. AF is a supraventricular tachyarrhythmia characterized by uncoordinated atrial activation with consequent deterioration of atrial mechanical function [1]. AF is often related to increased atrial size, allowing a critical mass of anatomical substrate for the persistence of the disorganized electrical waveforms [2]. AF is an important risk factor for stroke, conferring an increasing risk up to 5% in sixty years old patients [1]. The prevalence of AF increases along with the age and reaches around 10% in population over 70 years old. The mortality rate of patients with AF is about double that of patients in normal sinus rhythm and is linked with the severity of underlying heart disease [1]. AF that terminates spontaneously is referred as paroxysmal AF. When it sustains if no electrical or pharmacologic cardioversion is applied it is called persistent AF [1]. Persistent AF frequently results in permanent AF [1, 3].

AF is characterized by irregular and frequently rapid ventricular response [1].On the electrocardiogram (ECG) of AF episodes, consistent P waves are substituted by rapid oscillations of fibrillatory waves. In the frequency domain, the spectrum of these fibrillatory waves possesses high spectral content around 6 Hz [4]. Recent studies prove that AF episodes can be characterized using time-dependent spectral properties of atrial activity (AA) [5]. Time-frequency analysis of the surface ECG has been also used in preceding works for monitoring and predicting antiarrhythmic drug effects in AF episodes [6]. Suitable methods based on time-frequency analysis have been successfully used to distinguish between terminating and non-terminating AF episodes [7, 8, 9]. In order to obtain suitable spectral analysis of AF episodes, their AA must be previously extracted [10]. This requires using nonlinear signal processing techniques such as Average Beat Substraction (ABS) [11] or Independent Component Analysis (ICA) [12].

In this work, a new method to discriminate between paroxysmal and persistent AF episodes is presented. The novelty of this method is the representation of time-frequency parameters on Poincaré [13, 14] plots as a new tool of decision. The main advantages of this new method are the low computational load and the visually easy interpretation of data.

2. Database

The signal database consisted of 30 surface ECG recordings of AF episodes which were properly annotated by cardiologists. Approximately half of the them were marked as paroxysmal AF and the rest as persistent AF. The former half is subsequently refereed as the T-group and the latter as the N-group. These recordings were of one minute in length and were previously extracted from 24-hours one-lead Holter recordings of AF patients. The original sampling rate (f_s) of the Holter systems was 128 samples per second, but ECG recordings were interpolated by a factor of 8 so that a f_s equal to 1024 resulted. The resultant time-domain higher resolution allowed us to obtain a better cancellation of the QRS complex and a higher length of parameter sequences. In the case of the T-group patients, AF episode terminates one second after the end of the one-minute registration. On the contrary, the termination of AF episode did not occur during the whole observation time in the N-group patients.

3. Methods

First, the Atrial Activity (AA) were extracted from the ECG registers, given that the analysis of previously separated AA makes easier the study of AF [12] and improves the information provided by time-frequency distributions [15]. There exist several techniques designed to extract the AA of AF episodes from ECG registrations. The limitation of having only one-lead ECG obliged us to discard those techniques based on the spatial diversity of multi-lead systems, such as blind source separation [12]. On the contrary, the average beat substraction technique [11] works efficiently with one-lead ECG. Therefore this was the technique chosen to extract the AA.

Second, the spectrograms of the extracted AA signals were calculated using Hamming windows of 4096 samples in length and 97% overlap. In order to facilitate the extraction of spectrogram parameters, cubic spline fitting was applied to each of the Fourier transforms composing the spectrogram. The cubic spline model obtained the best fitting in comparison with gaussian, polynomial, rational, Weibull, power and exponential models. The cubic spline fitting curve from the original data was interpolated so that the resulting frequency increment was $0.01Hz$. In this way, the peaks of the spectrogram were calculated more accurately. From four time-frequency parameters of every spectrogram we constructed four time-domain sequences. These parameters are the main peak frequency (f_{p1}), the second largest peak frequency (f_{p2}), and their respective peak magnitudes (A_1 and A_2).

Finally, the phase portraits (i.e. the Poincaré maps with the stroboscopic view [13]) of the aforementioned parameters were plotted. One phase portrait is consists of plotting each data point of a periodically observed magnitude versus its predecessor [13, 14]). The visual inspection of clusters in the phase portraits, helped by the insertion of a cursor as a graphical threshold, was used to decide if the AF episode was of paroxysmal or persistent nature.

4. Results

Figures 1 to 4 show examples of phase portraits of permanent and paroxysmal AF episodes for A_1, f_{p1}, A_2 and f_{p2} parameters. Both x and y axes are equally scaled in the paroxysmal and permanent episodes in order to facilitate the comparison. The same example of permanent and paroxysmal episodes were chosen in all four parameters. $A_1 - 1$, $f_{p1} - 1$, $A_2 - 1$ and $f_{p2} - 1$ stand for the value in the previous observation moment of A_1, f_{p1}, A_2 and f_{p2}, respectively.

The visual inspection of Poincaré plots of fp1 showed that both terminating and non-terminating episodes presented lineal discontinuous clustering along the diagonal of the graph. Nonetheless, in the case of non-terminating episodes clusters were concentrated close to the top right-hand corner of the graph. On the contrary, clusters were situated close to the bottom left-hand corner of the graph in the case of terminating episodes. As shown in figure 2, when a cursor was located at the place determined by the frequency of 5.5 Hz as a graphical threshold, the subdivision of the graph allowed us to distinguish between permanent and paroxysmal AF. More than 80% of episodes were correctly classified using this process.

In the rest of parameters we could not find any plot characteristic to differentiate between permanent and paroxysmal AF episodes. The similarity between phase portraits can be observed in figures 1, 3 and 4. In consequence, neither we could fix any threshold so that the percentage of correct classifications exceeded 50%. Therefore these parameters were considered to be irrelevant to the characterization of AF.

5. Conclusions

To sum up, the Poincaré plots can be used as a reliable and practical tool in predicting the evolution of AF when the parameter f_{p1} is considered, what is consistent with the mainly decreasing evolution of f_{p1} in terminating AF episodes. More than 80% of cases were correctly classified by this new method. Further research based on Poincaré plots and nonlinear time series analysis could improve present results. The visual interpretation of data and the low computational load are the main advantages of this method, which could be useful to the clinical practice.

Acknowledgements

This work was partly supported by the projects 20070086 from the R+D+i Vice-rectorate of the Valencia University of Technology, GV06/299 from Consellería de Empresa, Universidad y Ciencia de la Generalitat Valenciana and TEC2007–64884 from the Spanish Ministry of Education and Science.

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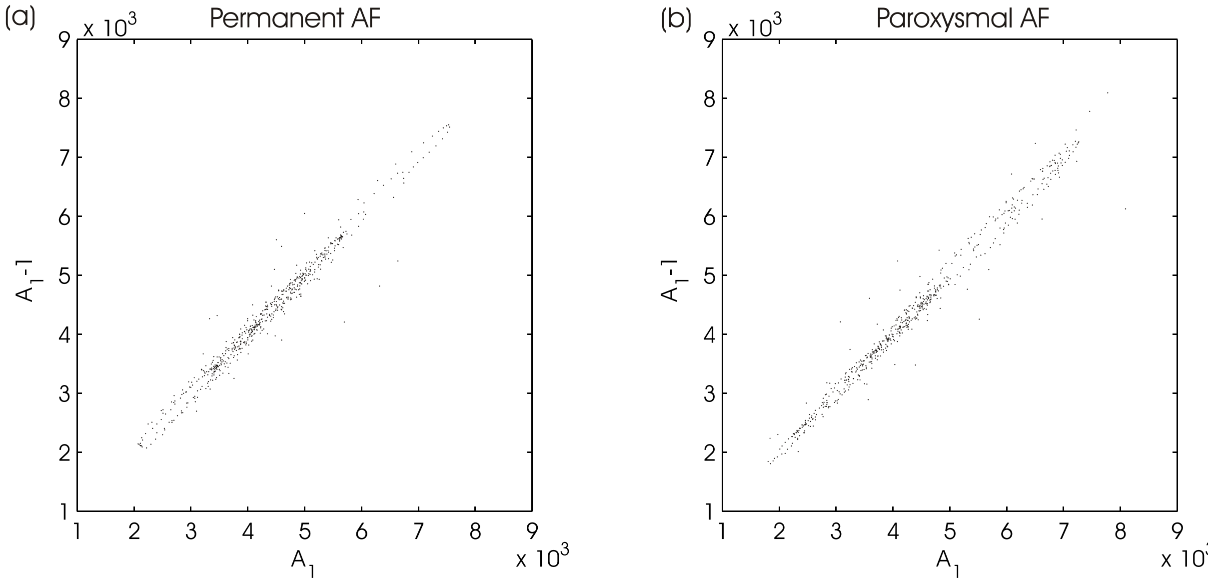

Figure 1. Example of A_1 phase portraits of (a) permanent AF episode, (b) paroxysmal AF episode.

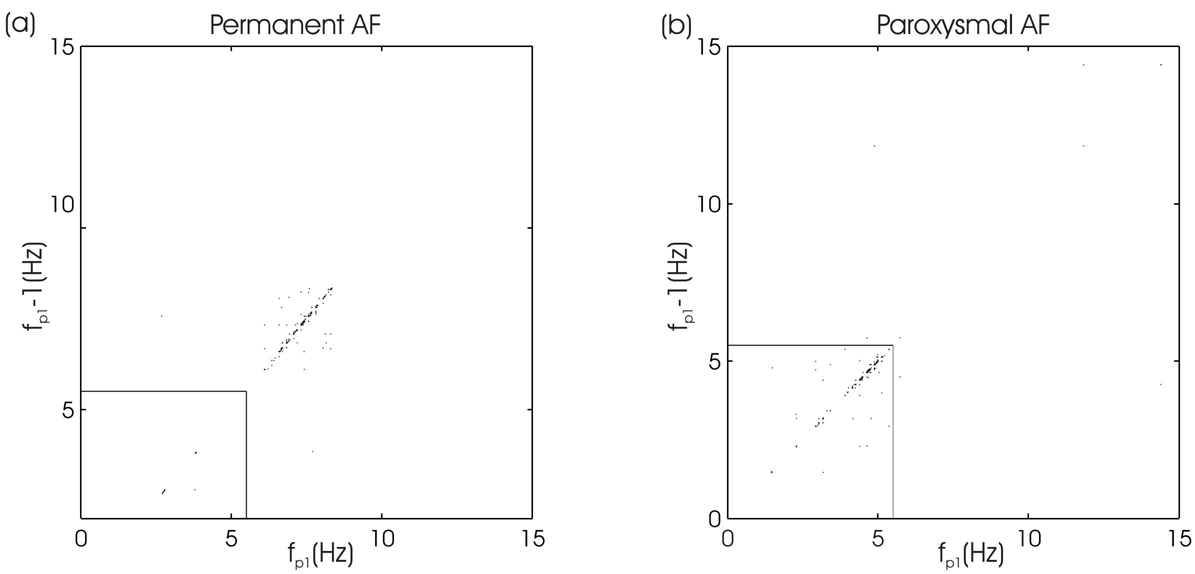

Figure 2. Example of f_{p1} phase portraits of (a) permanent AF episode, (b) paroxysmal AF episode.

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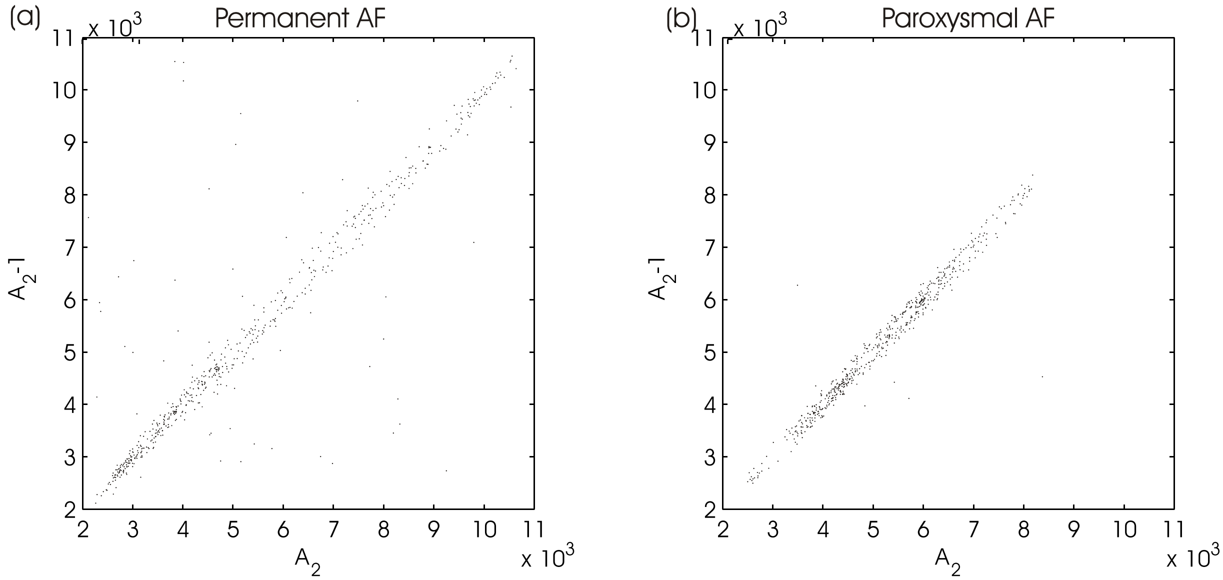

Figure 3. Example of A_2 phase portraits of (a) permanent AF episode, (b) paroxysmal AF episode.

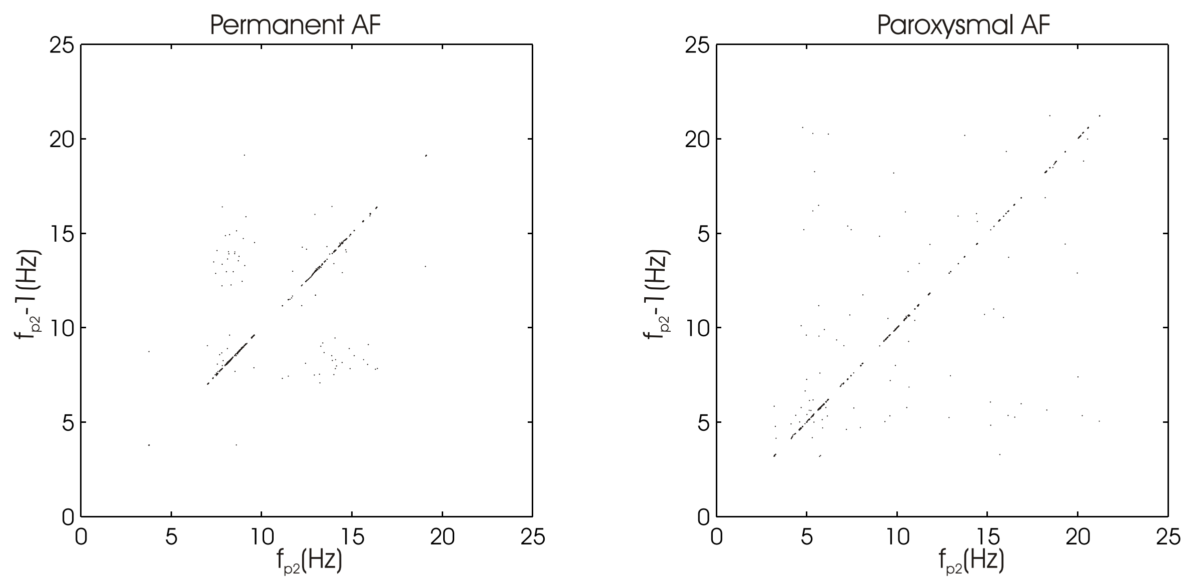

Figure 4. Example of f_{p2} phase portraits of (a) permanent AF episode, (b) paroxysmal AF episode.

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