Analysis of P-wave Changes for Prediction of Atrial Fibrillation Episodes

Cristina Moreno[1,2], Alba Martín Yebra[2], Aleksei Savelev[3], Pyotr Platonov[4], Pablo Laguna[1,2], Juan Pablo Martínez[1,2]

[1] Biomedical Signal Interpretation & Computacional Simulation (BSICoS)
Aragon Institute of Engineering Research, (I3A)
University of Zaragoza, Mariano Esquillor s/n, 50018, Zaragoza, Spain.
Tel. +34-976762707, e-mail: cmorenoa@unizar.es
[2] Centro de Investigacion Biomédica en Red – Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN)
[3] St. Petersburg State University, St. Petersburg, Russia
[4] Department of Cardiology, Lund University Hospital, Lund, Sweden

Abstract

The aim of this study is to assess the value of P-wave morphology markers in sinus rhythm to predict the imminence of atrial fibrillation (AF) episodes in patients with paroxysmal AF. P-waves get more complex, less periodic and wider when the AF episode approaches.

Introduction

Atrial fibrillation (AF) is the most frequent arrhythmia in clinical practice. The aging of the population has made it one of the most serious health problems in developed countries [1]. It usually initiates as a paroxysmal activity (PxAF), with the subject having sinus rhythm, with interleaved AF episodes.

The objective of the study is to evaluate the observations made in [2], where it was hypothesized that slower conduction in the atria and the presence of fibrosis in the atrial myocardium, both associated to AF, lead to P waves widened, more complex and with increased rugosity.

Methods

Database

The dataset contains 37 ambulatory ECG recordings from subjects with PxAF, recorded at the state University of St. Petersburg, Russia [3]. Two records were discarded due to poor signal quality and the presence of too many abnormal beats.

Thirty-one of the analyzed subjects had 3-lead recordings with a sampling rate of 250 Hz, the remaining four subjects had 12-lead recordings with a sampling rate of 257 Hz.

ECG Pre-processing

Baseline wander was attenuated at the ECG by applying a forward-backward linear 4th-order Butterworth high-pass filter with cutoff frequency of 0.5 Hz [3]. A low-pass filter with the same technique and cutoff frequency of 50 Hz was used to remove high-frequency muscular noise.

ECG Segmentation

Preliminary annotation of AF episodes was available [4] based on QRS detection with a wavelet-based algorithm [5] followed by AF detection based on fuzzy logic [6]. Thereafter, manual review was performed to finalize the annotation process accomplished by an expert on AF analysis. The recordings were segmented into 5-minute-duration excerpts, taken at 60, 30 and 5 minutes before the onset of each selected AF episode (Figure 1). Episodes not preceded by an AF-free interval of at least one hour were discarded.

P-wave extraction

For each analyzed excerpt, beats are extracted and aligned considering the QRS fiducial point as the reference.

From each k-th beat of each l-th lead we segmented a time window of 160 ms, starting 280 ms before the QRS mark, to ensure it includes the whole P wave.

Analysis of Principal and Periodic Components followed by beat averaging

Since P waves have typically low signal-to-noise ratio (SNR), we apply linear spatial transformations aiming at improving the SNR by exploiting spatial

redundancy in multilead ECG recordings. We used two processing methods, based on the analysis of principal (PCA) and periodic components (πCA) [7].

The PCA method uses a spatial linear transformation, where the first principal component is the one maximizing the energy of the P-wave. The πCA maximizes the m-beat periodic structure of the P-wave (with m=1 in this case). Then, the average beat of each of the first three principal/periodic components was computed.

Morphological P-wave features

We studied the following features: power of the i-th transformed component, $\mathcal{P}_i^{\Psi}$, relative power of the second-to-first component, $\mathcal{P}_2^{\Psi,r}$, relative power of third to-first plus second component, $\mathcal{P}_3^{\Psi,r}$, power of the P-wave after high-pass filtering with a 30 Hz cut-off frequency, $\mathcal{P}_1^{\Psi,HF}$ $\Psi\epsilon\{PCA, \pi CA\}$ (as a measure of rugosity) as well as the P wave duration in the first principal and periodic component D_m^{Ψ}.

Results and discussion

As shown at Table 1, $\mathcal{P}_2^{PCA}$ increased from 60 to 30 min (p = 0.015) and $\mathcal{P}_2^{PCA,r}$ increased from 60 to 30 (p=0.0061), and from 60 to 5 min (p = 0.012) previous to PxAF episodes.This can be related to higher atrial activity and a more complex loop as the AF episodes approached.

No significant differences were found in the high frecuency power by none of both methods.

A significant increase was found in the width of first principal component, D_m^{PCA}, from 60 min to 5 min (112.8 ms to 116.8 ms, p = 0.00017). The width of the first periodic component, $D_m^{\pi CA}$ also increased from 60 min to 5 min (105.1 to 108.9 ms p=0.011).This P wave widening could be an effect of the slowing down of the conduction or of a more complex propagation throughout the atria as AF approaches.

Conclusions

The study shows that P wave morphology significantly changes prior to the onset of AF episodes in PxAF, increasing the variability, making more complex P-wave loop, and enlarging the duration, which can be attributed to the de-structuring of the atrial wavefront.

Table 1 Features with present significant evolution at the selected time instants previous to PxAF events, Median [IQR] for PCA and πCA. Significant differences in italics.

Featur	60 min	30 min	5 min
P_2^{PCA}	*45.3 [67.3]*	*47.3 [62.0]*	47.2 [71.5]
$P_2^{PCA,r}$	*0.129[0.16]*	*0.142 [0.18]*	*0.147 [0.26]*
D_m^{PCA}	*112.8[10.5]*	116.7[12.6]	*116.8[22.9]*
$D_m^{\pi CA}$	*105.1[31.1]*	*108.0[31.1]*	*108.9 [31.1]*

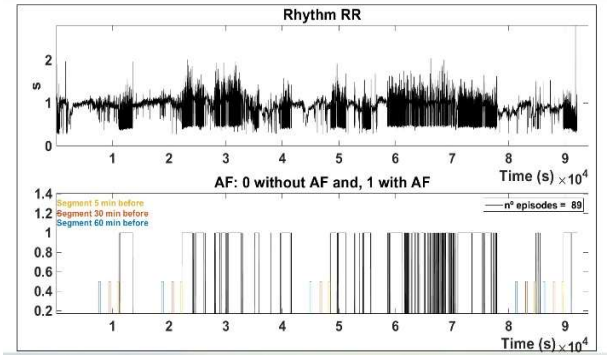

Figure 1. RR interval series in a recording from the dataset (top) and the selected AF episodes with their preceding analyzed excerpts at sinus rhythm (bottom)

REFERENCES (ISO 690-2013)

[1]. LASLETT, Lawrence, et al. The Worldwide Environment of Cardiovascular Disease. *Journal of the American College of Cardiology*. 2012, 60(25), S1-S4. Avaliable from doi:10.1016/j.jacc.2012.11.002.

[2]. PLATONOV, Pyotr. P-Wave Morphology: Underlying Mechanisms and Clinical Implications. *Annals of Noninvasive ElectroCardiology.* 2012, 17(3), 161-169. Avaliable from doi:10.1111/j.1542-474X.2012.00534.x.

[3]. LAGUNA, Pablo and SÖRNMO, Leif**.** *Bioelectrical Signal Processing in Cardiac and Neurological Applications.* Burlington: Elsevier Academic Press, 2005. 0-12-437552-9.

[4]. HENRIKSSON, Mikael., et al. Modeling and estimation of temporal episode patterns in paroxysmal atrial fibrillation. *IEEE Transactions on Biomedical Engineering.* 2021, 68(1), 319-329. Avaliable from doi:10.1109/TBME.2020.2995563.

[5]. MARTÍNEZ, Juan Pablo, et al. A Wavelet-Based ECG Delineator: Evaluation on Standard Databases. *IEEE Transactions on Biomedical Engineering,* 2004, 51(4), 570-581. Avaliable from doi:10.1109/TBME.2003.821031.

[6]. PETRÈNAS, A. et al. Detection of occult paroxysmal atrial fibrillation. *Med Biol Eng Comput.,* 2015, 53(4), 287-297. Avaliable from doi: 10.1007/s11517-014-1234-y.

[7]. MONASTERIO, Violeta, et al. A Multilead Scheme Based on Periodic Component Analysis for T-Wave Alternans Analysis in the ECG. *Annals os Biomedical Engineering.* 2010, 38(8), 2532-2541. Avaliable from doi:10.1007/S10439-010-0029-Z.