Improved Detection of Activation Timings in Endoatrial Electrograms through a Modified Sinusoidal Recomposition Method

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Abstract

Atrial fibrillation (AF) is the most common type of arrhythmia and the mechanisms that sustain it are not yet clearly identified. To target AF mechanisms, many theories on atrial electrical activation have been proposed. Since phase distribution of electrogram (EGM) changes over time is less affected by noise than EGM amplitude, phase analysis is one of the most robust method for identifying and quantifying spatiotemporal organization of fibrillation. In this paper we propose a new phase-based technique to detect atrial activation timings (AATs) and compared its performance versus manual annotation of AATs manually annotated by an expert cardiologist and versus classical methods based on Hilbert transform and sinusoidal recomposition. Detection of AATs from EGM signals in sinus rhythm applying the proposed technique overcomes the performance of classical methods and set the basis for its application on EGM in AF condition and phase map reconstruction.

1. Introduction

Atrial fibrillation (AF), is the most common type of arrhythmia and a leading cause of hospitalization and death [1]. Unfortunately, its therapy remains suboptimal. Catheter ablation is a non-pharmacological therapy that aims to restore sinus rhythm by eliminating tissue causing AF and is more effective than medications. Nevertheless its efficacy is limited, mainly because the mechanisms that sustain AF are not yet clearly identified. Indeed conventional ablation consists in isolating the left and right pulmonary veins, but this approach appears to be inefficient: in approximately 30% of patients the procedure is successful in maintaining sinus rhythm over the next year, depending on the type of AF and the severity of the underlying disease. The success rate is lowin patients who have had AF continuously for many years with secondary cardiac diseases. Success rate is high in patients who have intermittent episodes of AF without other heart disease. In some patients, ablation does not completely prevent AF but improves symptoms by reducing the frequency and severity of episodes or by making drug treatment more effective.

There are many theories on the mechanisms that sustain AF. “The rotors theory”, proposed by Narayan et al. [2], hypothesized that human AF may be sustained by electrical rotors (or reentrant circuits), whose elimination may improve outcome of AF ablation. The “rotor” is a stably rotating pattern (electrical spiral wave) of reaction and diffusion that surrounds a pivot point [3]. When a rotor is formed, the rapidly succeeding wave-fronts emanating from it propagate throughout the cardiac muscle and interact with anatomical and/or functional obstacles, causing fragmentation and new wavelet formation known as fibrillatory conduction [4]. “The disorganized mechanisms theory” hypothesizes that AF can be generated and sustained by disorganized electrical patterns, such as multiple wavelets, also linked to structural alterations occurring at the cellular level, including fibrosis [5].
Endoatrial electrograms (EGM) can be used to investigate these mechanisms. Recently, full contact basket catheters allow EGM recordings in different areas of the left atrial endocardium simultaneously. Through EGM processing, reconstruction of electroanatomical maps based on the detection of atrial activation timings (AATs) is possible. AATs are identified as the timing of phase inversion of the signal that corresponds to the transition of its phase from $-\pi$ to $+\pi$. The objective of this study was to develop and validate a robust method based on phase analysis of the endoatrial EGMs in order to detect AATs.

2. Methods

2.1. Data acquisition

Six patients with paroxysmal AF, aged 37 to 75 were enrolled in the study. All patients underwent an ablation procedure, and a 64-pole basket catheter (Constellation, Boston Scientific, Natick, Massachusetts) was used to acquire the unipolar electrograms in the left atrium (LA). The catheter is composed of 64 platinum-iridium electrodes mounted on eight flexible, self-expanding splines. After catheter insertion in the atrium, the catheter opens, and all electrodes touch the cardiac chamber wall, acquiring simultaneously longitudinal and circumferential signals.

Signals were processed using custom software developed in MatLab software (Mathworks, Natick, MA; USA).

2.2. EGM processing

During the ablation procedure we encountered some problems in catheter positioning; in some patients the catheter did not completely open in the atrium and some electrodes did not touch the wall of the cardiac chamber. Consequently, considering a threshold defined as the sum of mean electrode-wall distances and the corresponding standard deviation, we excluded from the analysis the electrodes that were distant from the wall more than 13 mm. In addition, in some patients the catheter covered only part of the chamber and, for a complete sampling of the LA, EGM signals were acquired by moving the catheter during ablation procedure (Figure 1).

The total number of acquisitions was 11 and the total number of processed signals was 461.

The signals were then filtered at 0.3Hz to 80 Hz (Figure 2). Far-field QRS complexes were subtracted from the unipolar electrograms by a single-beat cancellation method. A template of the ventricular far-field potential was obtained by averaging all time windows of the LA electrograms around R-wave detected in the ECG signals. The far-field ventricular potentials were removed by subtracting the template from the corresponding time windows in the LA electrograms (Figure 3).

To identify atrial activity, three different computational approaches were implemented. The first computational approach to analyze the electrical pattern is based on the Hilbert Transform (HT) of the electrograms and the instantaneous phase [6]. The second one is based on the recomposition of the electrogram from sinusoidal wavelets (SR) as proposed by Kuklik [7], with the amplitude proportional to the negative slope of the electrograms. The atrial activities were identified in correspondence of the phase inversion of the recomposed signals.

In addition, a new technique (NDSR) based on a modified version of the sinusoidal recomposition was implemented. Considering the typical morphology of the atrial activations, the sinusoidal wavelets were only generated in correspondence to the negative deflections that satisfy some conditions on the negative derivative, the amplitude and the duration. These resulting points were used to locate a window of fixed size in which the point with the maximum negative derivative corresponded to the timing of the phase inversion.

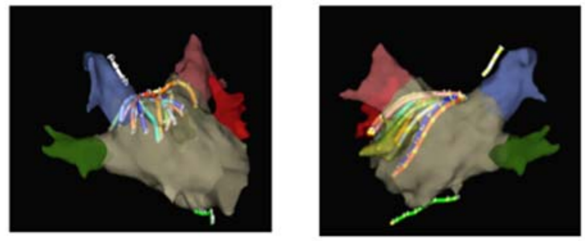

Figure 1. The figure shows two different positions of the Constellation catheter during an ablation procedure.

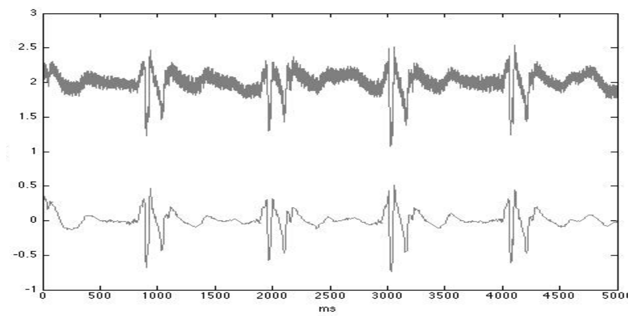

Figure 2. An example of row signal (top tracing) and filtered signal (bottom tracing).

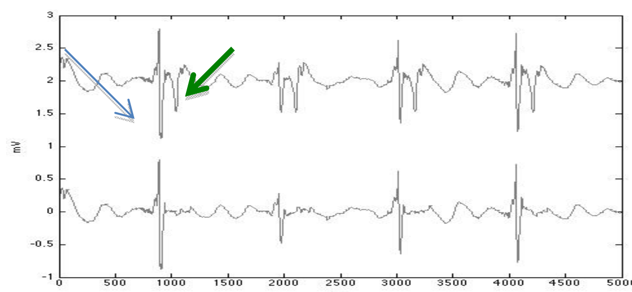

Figure 3. An example of electrograms with/without the ventricular far-field (up tracing/bottom tracing) . The green and blue arrows indicate the ventricular and atrial activity respectively.

3. Results

An example of detection of the atrial activations with the three methods is shown in Figure 4, 5 and 6:

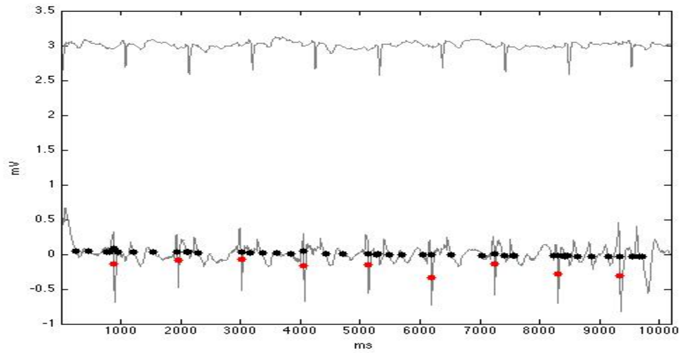

Figure 4. Example of the results obtained applying the HT based method. The figure shows ECG (top tracing) and a unipolar electrograms (bottom tracing). The black points represent the local activations as indicated by the algorithm in correspondence of the phase inversions, the red points represent the real activations as manually annotated.

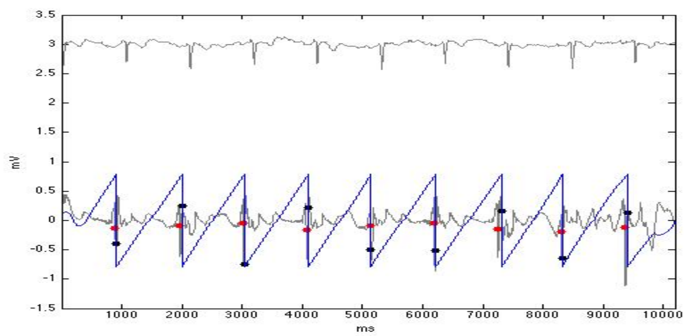

Figure 5. Example of the results obtained applying the SR based method. The blue line shows the phase inversions of the signals computed on the recomposed signal. Black points represent the detected local activations; red points represent the real activations as manually annotated.

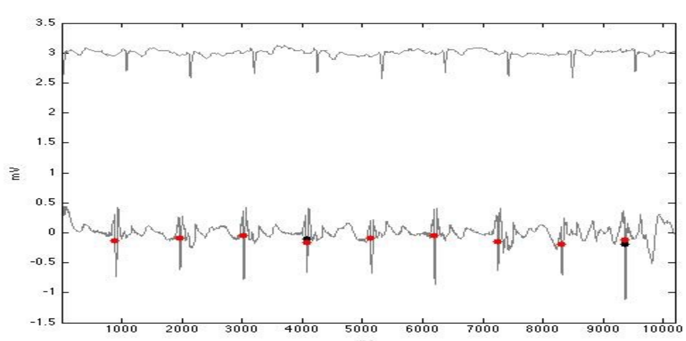

Figure 6. Example of the results obtained applying the NSDR based method. Atrial activations computed by the proposed algorithm are superimposed to manually annotated activations.

Comparison between AATs detected on a segment basis in 461 signals in sinus rhythm (5252 AATs in total) applying the three techniques is reported in Table 1.

	AAT detected	TP	FP	FN	Se (SD)	PPV (SD)
HT	30491	3424	27067	1816	63.2 (19.8)	11.1 (2.5)
SR	5339	1577	3762	3663	29.3 (10.7)	28.5 (9.3)
NDSR	5207	4359	848	881	82.6 (8.9)	83.2 (8.5)

Table 1. Results of the comparison between AATs detected applying the three phase-based algorithms, compared to AATs manually annotated. TP: true positive; FP/FN: false positive/negative; Se: sensitivity; PPV: positive predictive value.

Mean cycle length duration (MCLD), computed applying SR and NDSR showed an error of 5.1%±4.2% and 3.2%±3.4%, respectively.

A preliminary result of the application of the NSDR method in AF condition is shown in figure 7.

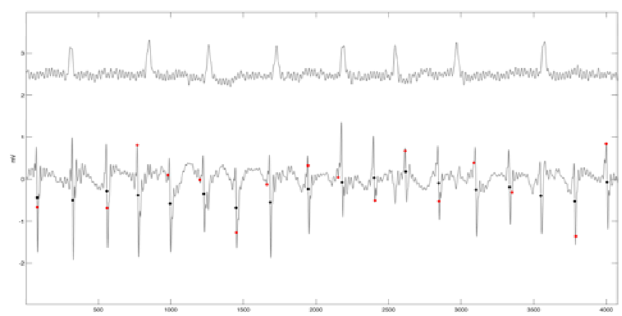

Figure 7. An example of the application of the NDSR method in AF condition.

4. Conclusion

Phase analysis is one of the most robust method for identifying and quantifying spatiotemporal organization of fibrillation.

This study proposes an improved method for signal phase reconstruction and atrial activation timings (AATs) detection. In particular three different computational approaches to identify the atrial activities in sinus rhythm were implemented. Results on AATs detection in NDSR method show the proposed technique overcomes the performance of standard techniques. In particular the performance of the HT method was surprisingly poor due to the very high number of false positive detections. This result could be linked to the presence of many small negative deflections recognized by the HT as phase inversions. Preliminary results on AF signals are promising and future developments include the phase map construction in sinus and AF condition in order to investigate the AF mechanisms.

References

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