Teager Energy Based Approach to Detect Atrial Peaks to Predict Atrial Fibrillation Recurrence

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Abstract

Radiofrequency catheter ablation is currently used widely and successfully to treat atrial fibrillation (AF), whose success is limited in part by uncertainty in the mechanisms that sustain AF. AF intracardiac recordings were registered from the right atrium (RA) and left atrial (LA) in 41 patients immediately before AF ablation procedure. They were divided in 2 groups according to AF recurrence outcome 3 months after ablation procedure: 26 of them remained in sinus rhythm and the other 15 turned back to AF. There was no statistically significant difference between clinical parameters from recurrent and non-recurrent AF patients in both groups. Atrial peaks were detected from the envelope obtained by Teager Energy operator. Results showed differences between maximum of atrial fibrillation cycle length in the RA in both groups, with shorter atrial intervals in the group without recurrences in AF (p=0,03). Moreover, differences between both atria were found in AF non-recurrent patients, higher atrial intervals in the LA (p=0.04), nevertheless not statistical significant differences were found recurrent AF group. High frequency values, especially without a gradient between both atria, predict AF recurrence. It suggests that when the atrial electrical activity is more irregular and similar in both atria, the reversion to sinus rhythm is more difficult.

1. Introduction

Atrial fibrillation (AF) is the most common abnormal heart rhythm encountered in clinical practice. During AF, the atria fibrillate and create an irregular rhythm, as consequence recordings of electrograms have demonstrated short and variable fibrillation intervals during AF. Prior studies of AF cycle length in animals and humans have emphasized its role as a surrogate measure of local atrial refractoriness [1-3].

Several drugs effectively restore and maintain sinus rhythm in patients with AF, nevertheless curing AF by catheter ablation is based on generating electrical barriers in various sites of the atria by altering the tissue properties in the vicinity of the ablating catheter tip. Most current techniques target the pulmonary veins (PVs) to isolate these dominant sources of activities [4,5].

Although success rates of sinus rhythm restoration after pulmonary vein ablation are promising, many patients are at highest risk for recurrences. In fact, AF recurrence rates after ablation procedure are still high [6,7]. Experts of the Task Force for the Management of AF of the European Society of Cardiology recognized that AF recurrence rates are markedly underestimated [8]. Therefore, the identification of subjects at high risk of AF recurrence would have important clinical implications.

Experimental mapping studies have shown that the AF cycle length (AFCL) is highly correlated with local refractory periods [9], shortens with maintenance of AF [10].

This study investigates the variation of AFCL along atria before pulmonary vein isolation. In three months follow-up AF ablation procedure, some of these patients had recurrences in AF and other patients who maintained sinus rhythm.

The main goal of this paper is to provide information related to AF recurrence from atrial activation intervals. Teager Kaiser operator was applied to extract atrial intervals have been used to identify sites of high-frequency activity maintaining AF [11]. This parameter has been also used with intracardiac AF recordings to assess if there are differences between atrial activations from dipoles located in both atria in the non-recurrent and recurrent AF groups.

In addition, in this study we analyse the recurrence outcome of paroxysmal and persistent AF patients in a three months follow-up and will relate these results to atrial activations extracted from intracardiac signals from both atria.

2. Materials

Intracardiac recordings during AF before ablation procedure and during the anaesthetic effect were taken from 22 AF patients (9 paroxysmal AF and 13 persistent AF) submitted to an ablation procedure. The main age was 53±12 years, 73% male, and mean left atrial size was 44.5±9.8 mm. In the paroxysmal AF group. A 24-pole catheter (Orbiter, Bard Electrophysiology, 2-9-2 mm electrode spacing) was inserted through the femoral vein and positioned in the right atrium (RA) with the distal dipoles into the coronary sinus (CS) to record left atrial (LA) electrical activity as well. The medium and proximal group of electrodes were located spanning the RA free-wall peritricuspid area, from the coronary sinus ostium to the upper part of the interatrial region. Using this catheter, 12 bipolar intracardiac electrograms from the RA (dipoles from 14-15 to 23-24) and LA (dipoles 1-2, 3-4 and 5-6), were digitally recorded at 1 kHz sampling rate (16 bit A/D conversion; Polygraph Prucka Cardio-Lab, General Electric). Thirty to 60 seconds recordings from paroxymal and persistent AF patients were analysed and compared. Four of these electrodes were located at the RA and 4 more at the LA were analyzed. All patients were monitored after ablation, and were divided in 2 groups according to AF recurrence outcome: 11 of them remained in sinus rhythm (SR), whereas the other 11 turned back to AF, 4 with paroxysmal AF and 7 with persistent AF.

3. Methods

The method can be divided into three main processing steps: envelope detection, atrial peaks detection and characteristic atrial activity intervals during AF.

3.1. Teager-Kaiser Energy Operator

The energetic domain describes the features related to the energy or the power of the data. These features combine the information of multiple points of the time series with nonlinear operations. An alternative approach in order to obtain the instantaneous characteristics of the vibration decomposed signals, is to use an energy tracking operator to estimate the energy of the signal, proposed by Teager and Kaiser [12] for the estimation of the amplitude envelope and instantaneous frequency for simultaneous modulation of amplitude and frequency. It is more sensitive to noise but mathematically linked to the energy of a sine wave, defined as a function of the product of its amplitude and its frequency. Teager’ s operator has been apply to the detection of peaks for the estimation of foetal heart rate from phonocardiographic signals [13], as well as for the analysis of images [14] and the voice and ECG signals to extract the energy content [15,16].

As Teager-Kaiser energy operator technique detects a sudden change of the energy stream without any priori assumption of the data structure, it can be utilized for vibration based condition monitoring (non-stationary signals). Then, Teager-Kaiser operator offers excellent time resolution because only three samples are required for the energy computation at each time instant.

For a discrete time signal x(n) (where n is the discrete time index), using difference to approximate differential, Teager-Kaiser energy operator can be proposed as [17]:

$$\Psi[x(n)] = x(n)^2 - x(n-1) \cdot x(n+1) \tag{1}$$

As at any instant, only three consecutive samples are needed to estimate the instantaneous Teager-Kaiser operator, it is adaptive to the instantaneous changes in signals and is able to resolve transient events.

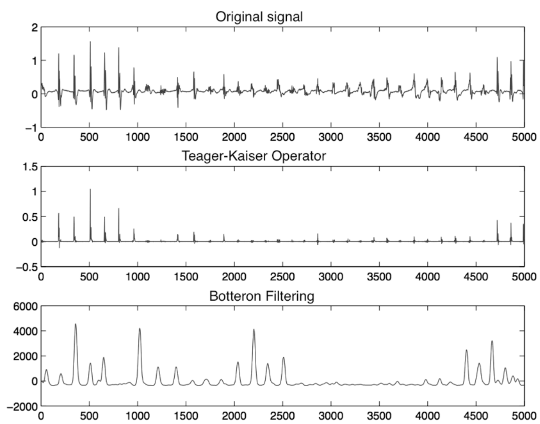

Figure 1. Atrial peaks were detected by Botteron filtering or Teager Kaiser energy operator.

3.2. Dominant Atrial Cycle Length

Subsequent to atrial activations detection with Teager-Kaiser operator, AFCL was calculated by subtracting the local activation time between two adjacent local activations, along the atria before ablation. Its variability was determined, and minimum, mean and median AFCL values by the difference between interatrial peaks intervals measurements before ablation. Interel ectrogram intervals lower than 100 ms were excluded from analysis. This usually eliminated the computer's picking both deflections; however, this was verified manually by a check of adjacent sites.

3.3. Statistical Analysis

Comparison between groups was performed with either Student’s t test or the Wilcoxon rank-sum test. Categorical variables were compared by use of Fisher’s exact test. Sequential data measurements were analyzed by repeatedmeasures ANOVA. Statistical significance was established at $P<0.05$.

4. Results

4.1. Analysis of differences between both groups

Median atrial activity intervals showed statistical significant differences between both groups in the right atrium (RA), with 176:51 ± 38:91 ms in the non-recurrent AF group vs. 155:61 ± 21:85 ms in the group with recurrences. Non differences were found along the left atrium (LA) between both groups.

4.2. Analysis of differences between both atria

Differences between both atria were found only in the group with not recurrences in AF.

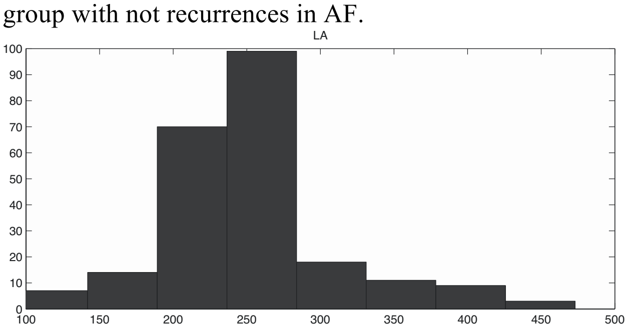

Figure 2. Non-recurrent AF patient AFCL histogram from a dipole located in the LA.

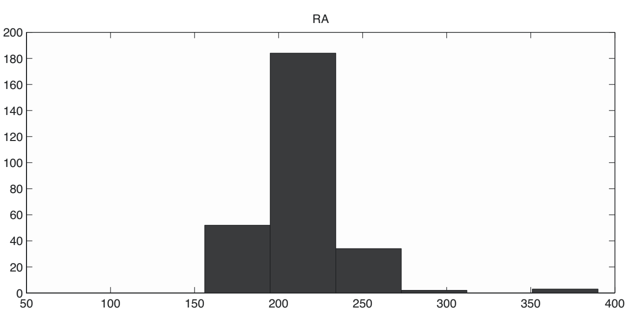

Figure 3. Non-recurrent AF patient AFCL histogram from a dipole located in the RA.

LA intervals have more dispersion, or variability than RA intervals in the group with recurrences in AF, with 297.84 ± 54.24 ms in the LA and 254.48 ± 57.40 ms in the RA. Figures 2 and 3 show this result.

Moreover, differences in median, mean, maximum and standard deviation of AFCL were found between the LA and the RA in patients with non-recurrences in AF (Figures 4 and 5).

Furthermore, there were not differences along the atria in patients with paroxysmal AF or persistent AF.

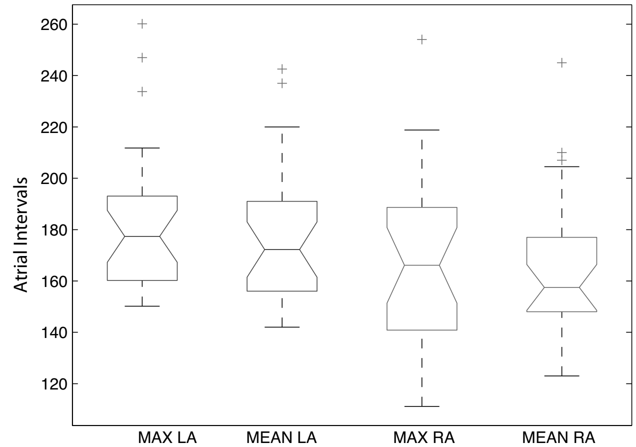

Figure 4. Maximum and mean atrial intervals were shorter in the RA (right) than in the LA (left)

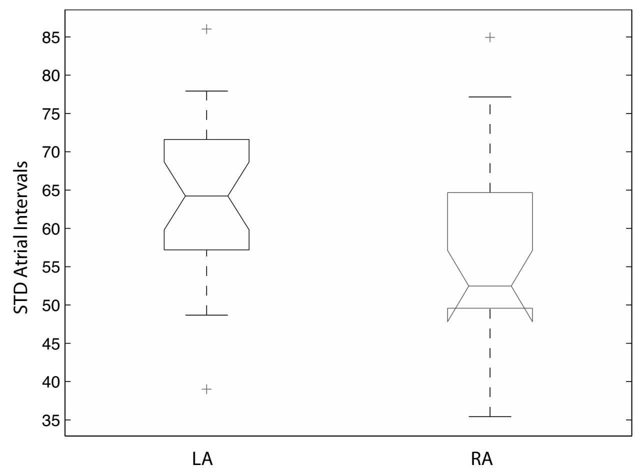

Figure 5. Atrial intervals standard deviation was shorter in the RA (right) than in the LA (left)

5. Discussion

Ablation is a curative treatment for AF, but has its limitations, including failure rates and recurrences [18]. The search for predictors of AF ablation success and AF recurrence is currently of high clinical interest. Just to mention few recent works, the dominant atrial frequency has been reported to play a role as a predictor of AF ablation outcome, where long cycle lengths were responsible for the organized monomorphic tachycardia, whereas the shortest cycle lengths between resulted in an ECG pattern of AF [19].

Results described provide some predictive information regarding the recurrence outcome after 3-months follow-up. Each AFCL was calculated by subtracting the local activation time between two adjacent local activations.

In studies involving the frequency domain, it is more convenient to work with Teager Operator Energy as a peak-detector than with an energy detector. During AF, atrial cycle length measurements show variability along the atria. This operator faithfully tracks all parts of the time-changing amplitudes.

Atrial activation in the group with recurrences showed smaller atrial activation intervals along the RA than the group with that maintenances sinus rhythm patients that maintenance sinus rhythm. Patients within the recurrent AF group did not show differences between atrial intervals from dipoles located in both atria. Maintenance of sinus rhythm is associated with differences in atrial activation intervals along the atria, with more variability and higher values along the LA, these results are consitent with previous studies.

These findings are consitent with previous studies [20,21] with differences between atrial activity along the atria in the patients with non recurrences in AF and lower main frequency in RA compared with recurrent AF group.

Acknowledgements

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