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Optimization of novel spectral estimator for fractionated electrogram analysis is helpful to discern atrial fibrillation type

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ABSTRACT

Introduction: Paroxysmal versus persistent atrial fibrillation (AF) can be distinguished based on differences in the spectral parameters of fractionated atrial electrograms. Maximization of these differences would improve characterization of the arrhythmogenic substrate. A novel spectral estimator (NSE) has been shown previously to provide greater distinction in AF spectral parameters as compared with the Fourier transform estimator. Herein, it is described how the differences in NSE spectral parameters can be further improved.

Method: In 10 persistent and 9 paroxysmal AF patients undergoing electrophysiologic study, fractionated electrograms were acquired from the distal bipolar ablation electrode. A total of 204 electrograms were recorded from the pulmonary vein (PV) antra and from the anterior and posterior left atrial free wall. The following spectral parameters were measured: the dominant frequency (DF), which reflects local activation rate, the DF amplitude (DA), and the mean spectral profile (MP), which represents background electrical activity. To optimize differences in parameters between paroxysmal versus persistent AF patients, the NSE was varied by selectively removing subharmonics, using a threshold. The threshold was altered in steps to determine the optimal subharmonics removal.

Results: At the optimal threshold level, mean differences in persistent versus paroxysmal AF spectral parameters were: $\Delta DA = +0.371$ mV, $\Delta DF = +0.737$ Hz, and $\Delta MP = -0.096$ mV. When subharmonics were not removed, the differences were substantially less: $\Delta DA = +0.301$ mV, $\Delta DF = +0.699$ Hz, and $\Delta MP = -0.063$ mV.

Conclusions: NSE optimization produces greater spectral parameter difference between persistent versus paroxysmal AF data. Quantifying spectral parameter differences can be assistive in characterizing the arrhythmogenic substrate.

1. Introduction

Fractionated atrial electrograms are useful to characterize the arrhythmogenic atrial fibrillation (AF) substrate for catheter ablation [1–4]. Since fractionated electrograms are complex, frequency analysis is often used for characterization [4]. It has been shown that there are significant differences in the spectral parameters of paroxysmal versus persistent AF electrograms. It would be desirable to maximize these differences

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to best characterize the arrhythmogenic substrate, which may lead to improved catheter ablation paradigms. A novel spectral estimator (NSE) has been shown to provide greater distinction in spectral parameters acquired from paroxysmal versus persistent AF patients, as compared with the discrete Fourier transform (DFT) method [3]. The NSE has additional advantages as a spectral estimator over the DFT for certain applications, including robustness to noise and phase jitter [1–3]. It has also been used to successfully discern ventricular tachyarrhythmias at onset in canine postinfarction studies [5]. However, the NSE suffers from the presence of significant cross-terms and subharmonics, which changes the spectral background level and is therefore undesirable during spectral parameter measurement. In prior work, these components were removed by imparting antisymmetry to all basis vectors used to form the NSE power spectrum [2,4]. In so doing, subharmonics were eliminated. This resulted in some improvement in the ability of NSE parameters to discern fractionated electrograms recorded from paroxysmal versus persistent AF patients. Yet, antisymmetry was imparted indiscriminately to all basis vectors used to generate the power spectrum. In the current study, we sought to determine whether selective impartation of antisymmetry could improve the ability of NSE to discern fractionated electrograms acquired from persistent versus paroxysmal AF patients.

2. Method

2.1. Clinical data acquisition

The data used for this study was obtained retrospectively with the approval of the Institutional Review Board of Columbia University Medical Center (CUMC). Patients were referred to the CUMC cardiac electrophysiology laboratory for catheter ablation of AF, and electrograms were recorded from the distal bipolar ablation catheter. The data from nine clinical patients with paroxysmal AF, having normal sinus rhythm as their baseline cardiac rhythm, were studied. In these patients, AF was induced by burst pacing from the coronary sinus or from the right atrial lateral wall. For data collection, the AF episode was required to continue for at least 10 min. Ten other patients had longstanding persistent AF without interruption for several months to many years prior to catheter mapping and radiofrequency ablation. For all patients, bipolar atrial mapping was performed using a NaviStar ThermoCool catheter, 7.5 F, 3.5 mm tip, with 2 mm spacing between bipoles (Biosense-Webster Inc., Diamond Bar, CA, USA). The electrogram recordings used for analysis were acquired from the distal ablation electrode using the General Electric CardioLab system (GE Healthcare, Waukesha, WI). The analog signals were filtered at acquisition from 30 to 500 Hz with a single-pole bandpass filter to remove baseline drift and high frequency noise. The filtered signals were digitally sampled at 977 Hz and stored. Although the high corner of the bandpass filter was slightly above the Nyquist frequency, negligible signal energy resides in this range [1]. Only atrial recordings identified as fractionated electrograms by two cardiac electrophysiologists were included for retrospective analysis. Fractionated electrogram recordings were obtained from two sites outside the ostia of each of the four pulmonary veins. Recordings were also obtained from the mid-posterior atrial wall, and from the anterior ridge at the base of the left atrial appendage. A total of 204 recording sequences of length greater than 16 s were analyzed from all patients.

2.2. Data analysis

The NSE power spectrum is constructed by first dividing the electrogram signal $\underline{x}$ into n segments of length w:

$$\underline{x}_N = \begin{bmatrix} \underline{x}_{w,1} \\ \underline{x}_{w,2} \\ \cdots \\ \underline{x}_{w,n} \end{bmatrix} \tag{1}$$

where underline indicates a vector, the length of signal $\underline{x}$ is N sample points, the length of segments 1, 2,. . ., n, are w sample points, and:

$$n = \text{int}\left(\frac{N}{w}\right) \tag{2}$$

with 'int' being the integer function (rounded down). The signal mean is then obtained as:

$$\underline{e}_w = \frac{1}{n}\sum_i \underline{x}_{w,i}, \quad i = 1 \text{ to } n \tag{3}$$

The power in the signal mean is given by:

$$P_w = \frac{1}{w} \cdot \underline{e}_w^T \cdot \underline{e}_w \tag{4}$$

The NSE power spectrum is plotted as:

$$\sqrt{n}P_{wRMS} = \sqrt{n}\sqrt{P_w} \tag{5}$$

where P_{wRMS} is the root mean square power, with units of millivolts, and the scaling term $\sqrt{n}$ is used to counter the falloff of the baseline level by $1/\sqrt{n}$ per number of summations n used for averaging [1]. The root mean square power is plotted versus frequency f, given by:

$$f = \frac{\text{sample rate}}{w} \tag{6}$$

where the digital sampling rate was 977 Hz for the atrial electrograms obtained for the study. NSE basis vectors $\underline{b}_{w,N}$ of length N are formed by repeating $\underline{e}_w$ from Eq. (3) for n times, thus:

$$\underline{b}_{w,N} = \begin{bmatrix} \underline{e}_{w,1} \\ \underline{e}_{w,2} \\ \cdots \\ \underline{e}_{w,n} \end{bmatrix} \tag{7}$$

where all $\underline{e}_{w,i}$, $i = 1$ to n are identical. In cases where $N \neq w \times n$ due to rounding in Eq. (2), $\underline{b}_{w,N}$ is padded at the end with additional elements of $\underline{e}_w$ so that its length is N. When a subset l