Frequency Coherence Mapping of Termination of Induced Canine Atrial Fibrillation

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Abstract

Multiple unipolar electrodes were used to measure and record right atrial activation in canine atrial fibrillation (AF) model. Twenty open-chest dogs with induced AF by extra-stimulation under continuous infusion of methyl- acetylcholine. After AF sustained for 5 minutes, 10 dogs received intravenous procainamide and 10 dogs received d,l-sotalol for AF termination. Unipolar electrograms were recorded at baseline and during infusion of antiarrhythmic drugs, using a 120-electrode array (electrode spacing is 3mm) placed on the right atrial free wall. In this study, we used magnitude-squared coherence in frequency (MSCF) mapping to show the frequency distribution during AF. The data were digitally filtered. The spectra were limited within 2-15Hz for AF signals. We chose each electrode as a reference, and established its MSC spectra with other signals. Then, from 120 MSC spectra at dominant frequency (DF) (MSC>0.5) of reference to compose a DF mapping. The mappings were added together for the same DF. We used the MSCF map to denote four periods: (1) normal sinus rhythm; (2) AF baseline; (3) before AF termination; (4) sinus rhythm following termination. The dominant area (DA) including SA node was chosen with the isochronal maps. The results show that the DA has characteristics different from other sites, when AF terminated. The signals of DA are regulated with frequency within 7~9 Hz ($p<0.05$) and have longer cycle lengths than other sites ($p<0.05$). When AF is converted to sinus rhythm, SA node will be re-controlled into the new tempo in the atrium. We demonstrated that an area contains the SA node would be the dominant area in AF termination. Increased organization of electrical activation in DA may be the underlying mechanisms of drug-induced termination of AF.

1. Introduction

Cardiac mapping is obtained from simultaneous electrical activations in numerous locations of the heart. Analysis of cardiac mapping entails extracting a particular time domain variable, the time of local myocardial activation from each recording channel, and plotting its value for each channel to obtain the isochronal map [1]. People used other analysis techniques involving transformation into frequency domain to help visualization and analysis. Magnitude-squared coherence (MSC) function, a frequency domain measurement of phase consistency between two signals, can quantify the levels of various arrhythmias [2].

Previous studies from other groups have described that coherence mapping is calculated from the average of each MSC spectrum from 0 to 50 Hz. Averaged MSC drops with distance for all rhythms, being most pronounced for fibrillation. MSC mapping may provide a long-term spatial organization of rhythms that can distinguish fibrillatory and nonfibrillatory rhythms. MSC values in AF signals are at most 0.5 and less [2,3]. According to the hypothesis about the mechanism of AF, the maintenance of AF depends on the presence of a number of simultaneous reentering waves, and the minimum size of a reentrant wave is related to the wavelength; the wavelength should be an important determinant of the occurrence of AF [4]. Increasing cycle length should decrease the number of the reentrant waves. The parameter of cycle length is regarded as a key point to estimate situation of local AF. People still use the cycle length to observe the period of AF.

In our study, we used MSC function and main-power frequency to make MSCF maps. MSCF map is attained by high coherence (MSC>0.5) at dominant frequency. We used cycle length and coherence to find the role of SA node in terminating AF.

2. Methods

All animal experiments were approved by the Veterans General Hospital, Taipei. Twenty mongrel dogs weighted 10 ± 5 kg were used. AF was induced by electrical stimulation and methyl-acetylcholine (0.5 μ g/kg/min) injected continuously to sustain AF. After 5 minutes of

fibrillation, 10 dogs received intravenous procainamide (15 mg/kg) and the other 10 dogs received d,1-sotalol (2 mg/kg) to terminate AF.

The 120 electrodes were arranged into 15×8 matrices, called electrode arrays, on the spoonly plastic plank. The electrodes are metallic dots that have conduction wires connecting to the computer. There is 3 mm between each two adjacent electrodes. The measurable area is about 21 mm ×42 mm. Recorded signals were amplified and filtered by Prucka Cardio Mapping System. It was used to record the epicardial signals of the right atrium (Figure 1). Signals were acquired with 1k Hz sampling rate. Hence, all 120 channels were decompressed in binary code by Prucka's program.

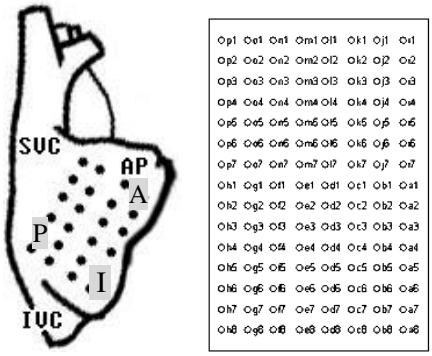

Figure 1. Mapping of the free wall of the canine right atrium (left graph) using 120-channel epicardial mapping electrodes. The electrodes were assigned from A to P (right panel). Position A is close to the right atrial appendage (AP), positions I and P are, respectively, close to SVC (superior vena cava) and IVC (inferior vena cava).

2.1. Signal processing

Magnitude-squared coherence (MSC) is a measure of the relationship between two different signals in frequency domain. It is defined as:

$$MSC(f) = \frac{\left|S_{xy}(f)\right|^2}{S_{xx}(f)S_{yy}(f)}$$

where $x(t)$ and $y(t)$ are the two simultaneous recordings. S_{xy} is the cross-power spectrum of $x(t)$ and $y(t)$. S_{xx}, S_{yy} are the power spectra of $x(t)$ and $y(t)$, respectively. The MSC value is between 0 and 1. If $x(t)$ and $y(t)$ have high relation, the MSC is near to 1. If these two signals are uncorrelated, the MSC is equal to 0. Each of the 120 records was digitally filtered using a second-order Butterworth filter (5-50 Hz), and data were taken simultaneously from the reference and all other channels. The frequency with maximum power was defined as dominant frequency (DF). From these data records, MSC spectra calculated from 120 locations were relative to reference, and each data was weighted with a Hamming window and FFT with 50% overlap was used to calculate the spectra.

2.2. MSCF map

The MSCF mapping was obtained by the methods described below (Figure 2):

(1) Selected one electrode among 120 electrodes as the reference channel.

(2)120 MSC spectra were computed from each electrode relative to the reference channel.

(3) Chose each magnitude that was more than 0.5 from those 120 MSC spectra at DF to from a DF mapping.

(4) Repeated the three steps above while each electrode was selected as the reference channel. Then we got 120 DF mappings.

(5) These 120 mappings were added together upon different DF.

(6) We used DF that had been counted frequently. The substituted mapping which was thus the distribution of DF named the MSCF map.

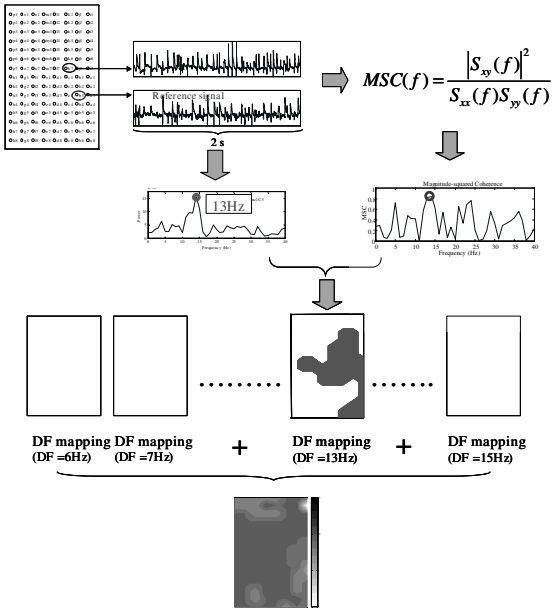

Figure 2. Flow chart of all steps made up the MSCF map.

2.3. Dominant area

We used the traditional method to contour an isochronal map and found the maximum of differential value for every epicardial electrode. The isochronal map

is shown in Figure 3. Then, a square area that including the earliest depolarization times was defined as DA. The SA node is included in DA. The dominant area of MSCF map will relate to the termination of AF in this study. DA was applied to analyse temporal and spatial variations when AF was going to cease.

3. Results

The frequency range of MSCF map is 2-15 Hz. The high coherence was found in the dominant frequency. Epicardial signals always recorded complete potential of cells, including the primary signals and also noise and interference. The MSCF map was adaptable to assay epicardial signals, because MSC has to greater than 0.5. It enhanced the dominant frequency of some electrodes that have the same source. For example, in Figure 4, there are six maps in which upper three maps are 6 seconds of AF without drugs and the lower three maps are 6 seconds before AF terminated. Each map consists 2 seconds of recorded data. All maps are color-coded according to grey table, with that the lightest color of grey indicating the smallest frequency and the darkest color of grey indicating the highest frequency. The MSCF maps are observed to have strong relationship to frequency with antiarrhythmic drugs or without. The first 3 MSCF maps on top have the distribution of high frequency and irregular patterns. The lower 3 maps have pure light color showing that it worked on unity frequency.

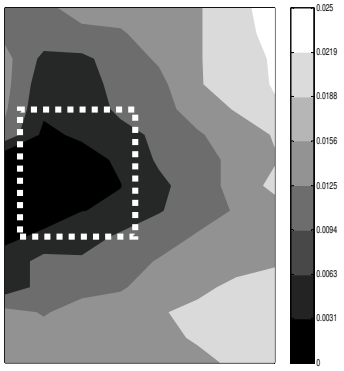

Figure 3. An example of isochronal map in sinus rhythm is shown. Finding the earliest depolarization of the right atrium corresponding to the area around SA node (dotted square). There are 24 electrodes (about 9×15 cm^2) enclosed by the dotted square.

As expected, during AF baseline without drug, the values of frequency (11.0±0.93Hz) were higher than after drug (8.85±0.69Hz) and had regular frequency in DA (Figure 5). In order to observe changes in frequency of the DA before and after drugs, there were three bands that were divided from the range of dominant frequencies (2-15Hz): A band (2-6Hz), B band (7-10Hz), and C band (11-15Hz). There were four situations: sinus rhythm before antiarrhythmic drug (SR BD), pacing induced AF before drug (AF BD), before AF termination (AF BT), return to sinus rhythm after drug (SR AD). We calculated the percentage of three bands allotted in the four situations. In Figure 5, before termination of AF (AF BT), it shows high percentage which is more than 50% in median frequency band (B band), and it has 82.5±15% in procainamide and 59.4±33% in d,l-sotalol in the right atrium. If DA is relative to adapted frequency band (7-10Hz) and regular distribution (more than 50%), AF could start to terminate. Depending on high percentage distribution, SR BD and SR AD belongs to A band, AF BD on C band, and AF BT on B band.

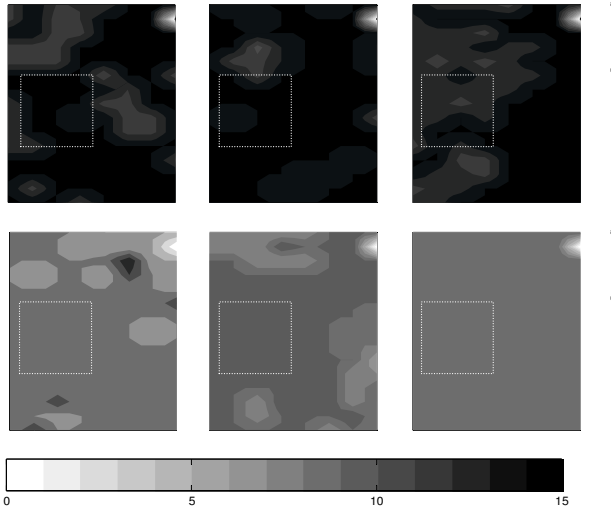

Figure 4. An example of MSCF map for a 2-s recording is shown. Upper 3 maps exhibit continuous 6 seconds for the situation in AF baseline signal. Lower 3 maps exhibit 6 seconds before AF termination. The white dotted square indicates the dominant area (DA).

For data acquisition in time domain, we started at 10 seconds before and after we injected antiarrhythmic drugs. To compare the variation of local cycle lengths during AF, we chose two sites: DA and another area with the same size (Figure 7). The cycle length were 73.3±8.9 ms and 73.0±8.0 ms, respectively, in the DA and other area during AF without drug. After injection of the drug, the cycle length increased in DA and the other area before AF termination (111.1±11.7 ms and 95.1±15.6 ms, respectively). After statistical analysis, the difference is significant between these two areas ($p<0.05$). Regarding the effects of procainamide and d,l-sotalol, procainamide made AF termination successfully for all ten dogs (100%), but d,l-sotalol infusion only terminated AF successfully in four dogs (40%).

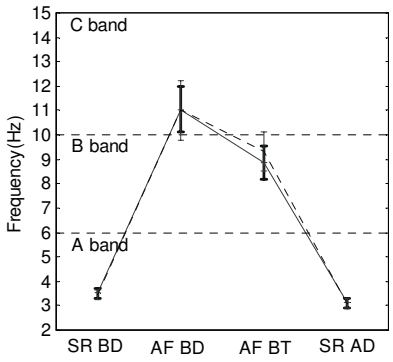

Figure 5. Three frequency bands distributed during four situations in DA. SR BD, SR AD are in A band. AF BD is in C band. AF BT is in B band. SR BD: sinus rhythm before antiarrhythmic drug, SR AD: sinus rhythm following termination, AF BD: pacing induced AF before drug, AF BT: before AF termination.

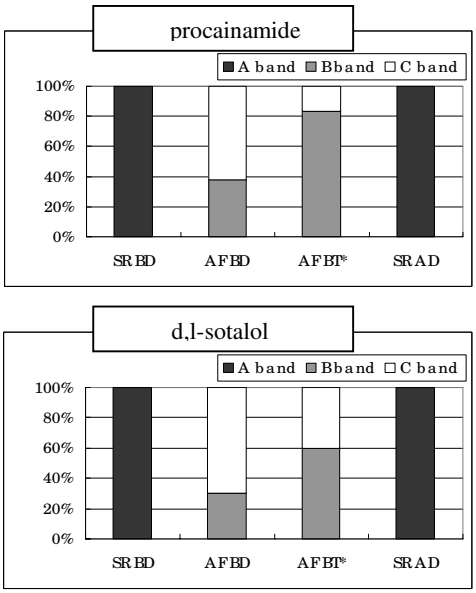

Figure 6. Statistical analysis of data focused on DA that 10 dogs received procainamide and 10 dogs received d,l-sotalol in four specific situations, sinus rhythm before drug (SR BD), AF before drug (AF BD), AF before terminated (AF BT) and sinus rhythm after drug (SR AD). DF is divided into three bands (A band: 2-6Hz, B band: 7-10Hz, C band: 11-15Hz).

4. Conclusion

In our study, using the dominant frequency of all electrodes and multi-reference redefined the coherence mapping, and emphasized the simultaneous of local AF signals. The MSCF map was calculated from many steps, but it could decrease the effect of noise and increase the coherence in unipolar electrograms.

The dominant area including SA node was defined for the first time. After the injection of antiarrhythmic drug, frequency was reduced to median frequency (7-10Hz), and the contraction of myocardium in DA was synchronized by SA node. When AF is converted to sinus rhythm, SA node will be re-controlled into the new tempo in the atrium. We determined that an area containing the SA node is dominant factor that decides whether AF shall terminate. Increased organization of electrical activation in DA may be the underlying mechanisms of drug-induced termination of AF.

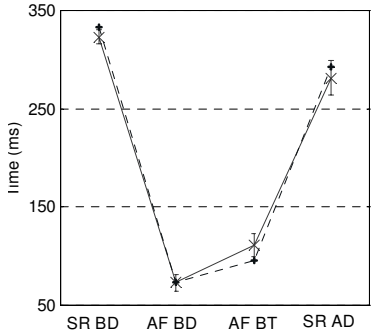

Figure 7. Variations of cycle lengths during AF returning to sinus rhythm. Dotted line is cycle length in DA; solid line is cycle length in other area. During AF BT, there were dissimilar cycle lengths in DA and in other area ($p<0.05$).

Acknowledgement

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