Methodology Improvement in Defining Characteristics of Atrial Fibrillation Termination

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Abstract

An atrial fibrillation (AF) analysis system based on the Laplacian potential was implemented and used to study the characteristic of AF termination. The computation of Laplacian potentials not only eliminated interfering of adjacent activities but also improved the activation detection as compared with bipolar electrograms. The results of activation cluster analysis indicated that, during AF, there were lots of small cluster in the Laplacian isochronal map. On the other hand, there were fewer clusters during normal sinus and the averaged size of cluster was larger. The results of correlation analysis suggested that the phase distribution of current flow vectors between adjacent beats were significantly more correlated during normal sinus (0.54 ±0.08) than AF (0.24±0.16). This correlation became higher toward the end of AF termination.

1. Introduction

To clarify the mechanism of termination in atrial fibrillation (AF) is important in developing methodology of treatment. However, using unipolar measurement system, the local activations in electrogram were interfered by remote activities and/or adjacent repolarizations. On the other hand, Ben He proposed the used of body surface Laplacian to map the cardiac electrical activities which not only improved the resolution but also enhanced the local activities [1]. The same mapping technique was used by Ruben Coronel in 2000 to study the electrogram during ventricular fibrillation [2]. Therefore, an improved methodology using Laplacian estimation to remove the remote activities and enhanced local unipolar electrograms was implemented. Additionally, two new analyses, the correlation of phase distribution of current flow vectors and isochronal cluster analysis was proposed to study the local characteristics of AF.

2. Methods

Electrograms of eight open chest canines were acquired using a 120 unipolar electrodes which were arranged in a 15×8 matrix. The electrode matrix was placed on the right atrium epicardium and the upper tip of electrode matrix was placed close to the SVC (superior vena cava). Signals were acquired using Pruka Computerized Cardiac Mapping System (Pruka) with a sampling rate of 1000Hz. At the beginning of the experiment, electrograms during normal sinus arrhythmia were recorded followed by continuous injection of Acetylcholine (ACH). AF was inducted by electrical stimulations. The stimulation interval was 300ms. When the inducted AF sustained for more than five minutes, a 28s AF electrograms were recorded. Intravenous infusion of Procainamide (sodium blocker) started after AF was successfully inducted.

Self-developed software was implemented using Borland C++ Builder to calculate the 2nd moment derivative from adjacent electrical activities [2]. An algorithm based on wavelet transform and dynamic threshold [3] was used to detect the local activation automatically. All the activation times were tabulated for further analysis. The resulting Laplacian potentials were reconstructed into 10 potential maps for each activation (Figure 1.a). In the potential maps, the time sequence starts from the upper left and goes down tile the fifth frame. The next five sequences start from the lower right and go up. To assemble the current flow vector map, the current flow vector at each electrode location was defined as the sum of Laplacian potential differences between the eight adjacent electrodes and that particular electrode (Figure 1.a). Instead of 10 vector maps, this study proposes the use of time space (TSP) mapping method [4] to accelerate the analysis of activation propagation. From the first frame of vector map, all the horizontal components at the same row of electrodes are summed to generate the first horizontal time space component. From the second frame of vector map, the second horizontal time space component was generated. Collecting all 10 horizontal time space components together, the horizontal direction time space map was created (Figure 1.b).

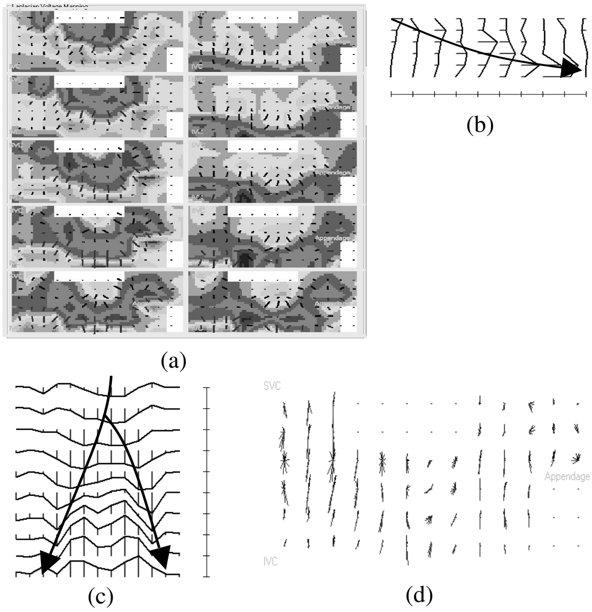

Figure 1. (a) Laplacian potential map and superimposed current flow vector map, (b) time space map (horizontal direction), (c) time space map (vertical direction) and (d) vector distribution map during sinus arrhythmia.

Likewise, by summing all the vertical component of current flow vectors at each column of electrodes, one vertical time space component can be generated. By collecting all 10 vertical time pace components together, the vertical direction time space map was created (Figure 1.c). At the same time, the current flow vectors at each electrode can be plotted together to generate vector distribution map (Figure 1.d) and the phases of each vector were tallied into vector phase histogram for further study. Furthermore, Laplacian isochronal maps were reconstructed and the number and size of activation clusters were studied. The activation cluster was defined when the activation time difference between two adjacent electrodes was less then 20ms they were classified in the same activation cluster.

3. Results

The effects of Laplacian can be easily seen in Figure 2, where Lead II ECG, original electrogram from one of the 120 electrodes and the corresponding Laplacian are in the top, middle and bottom panel, respectively. The conventional method to determine the occurrence of activations in the electrogram is to match the activities between Lead II ECG and electrogram and eliminates the activities that occur during ventricular activation period. However, this process can not distinguish local activation from nearby activities, denoted as 1 and 2 in Figure 2. For these two activations, both Lead II ECG and electrogram indicate atrial activities. However, the corresponding Laplaian signal depicts two different types of atrial components. One of

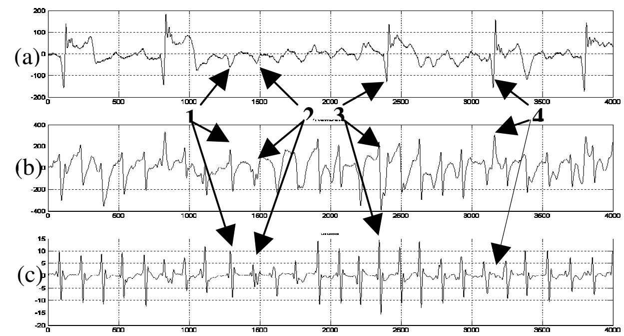

Figure 2. Effect of Laplacian. (a) Lead II ECG, (b) electrogram and (c) corresponding Laplacian signal.

them is larger and is considered as a local activation (1 in Figure 2) the other is much smaller and is considered as a nearby activation (2 in Figure 2). On the other hand, the activations close to ventricular activities, for example 3 and 4 in Figure 2, will be eliminated by the traditional method. However, the Laplacian signal indicates that there is still an atrial component at one of the instance (3 in Figure 2) but is not at the other (4 in Figure 2). Additionally, the overall appearance of activations in the Laplacian signal is much clearer, as compared to the electrogram, and is easier for auto activations determination.

The self-developed software used wavelet transform to further decompose the Laplacian signal into five wavelet scales. The dynamic threshold method was implemented to detect the activations automatically. The averaged cycling length for 8 canines was 128±9.68ms. From the constructed Laplacian potential maps, it was noticed that there were significant differences in the patterns of activation among different time segments of electrogram prior to the last activation before AF termination. However, it is difficult to quantitative describe these difference from the potential maps. Nevertheless, these differences may be easier to study using the TSP map. For example, for normal sinus, the activation started from the top and propagated to the bottom as illustrated in horizontal TSP (Figure 1.b). In the vertical direction, the activation started from the center and simultaneously transmitted to the left and right

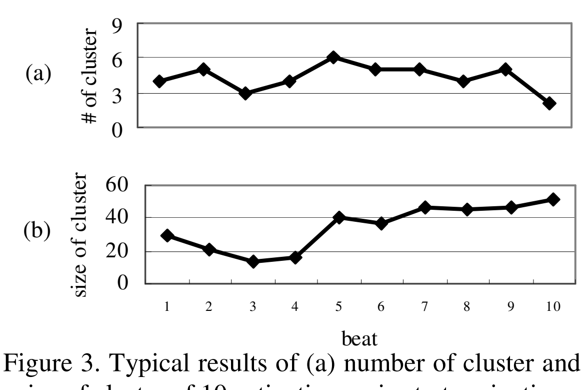

Figure 3. Typical results of (a) number of cluster and (b) size of cluster of 10 activations prior to termination.

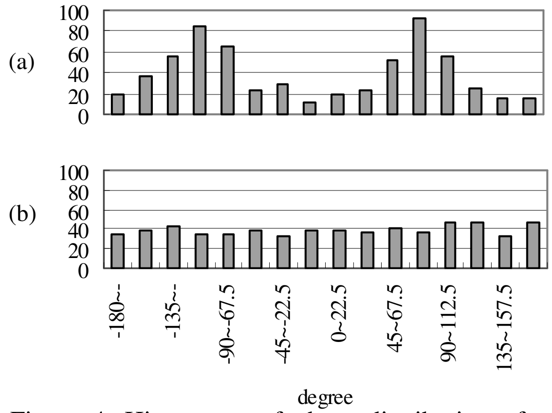

Figure 4. Histograms of phase distribution of current flow vector. (a) Normal sinus and (b) AF.

(Figure 1.c). Unfortunately, more data are needed to extract a consistent TSP pattern for AF.

On the other hand, it was proposed to study the number and size of activation clusters in Laplacian isochronal map. Three segments of electrogram, 10 activations in each segment, prior to last activation before termination, were examined and compared with the last activation before termination. It was found that the activation cluster became less and the size of cluster increased toward the termination (Figure 3). Furthermore, the cluster size and number ratio (CSNR) was defined as the size of cluster divided by the number of cluster in the same frame. The averaged CSNR for the three time segments were 7.09±1.04, 7.58±1.09, 9.55±1.58, respectively, and the CSNR for the last activation was 39.58±19.15. The CSNR is significantly higher at the last activation before termination. The significantly increased CSNR indicated that the multiple wavelets during AF merged into fewer large wavelets before termination.

In addition, it was noticed that, during normal sinus arrhythmia, the current flow vectors distribution were concentrated at 90 □ for repolarization and -90 □ for depolarization. In contract, the vectors distribution was widely dispersed in AF. The above mentioned phenomena can be seen from the histogram of vector phase (Figure 4). It was assumed that during AF there is little correlation between adjacent activations. On the other hand, current flow vectors will reorient toward 90 and -90 degrees before the end of termination. Thus, three segments of electrogram, 10 activations in each segment, prior to the termination, were examined. In the three segments, the averaged correlations between adjacent activations were computed in addition to the correlation between last activation before termination and the normal sinus. The averaged correlation of vector orientation between last activation and the sinus is 0.54 ± 0.08. However, in comparison, the correlations of the vector orientation between activations in AF were ranged from 0.16 to 0.24 (Table 1). These results indicate that the orientation of electrical current flow was unified toward the termination of AF.

Table 1. Correlation of vector orientation

Files	Seg. 1	Seg. 2	Seg. 3	Last beat vs. Sinus
A19F5	0.34	0.54	0.34	0.46
A20F15	0.16	0.06	-0.12	0.43
A20F17	0.30	-0.34	0.30	0.57
A20F19	-0.14	-0.01	0.25	0.68
A20F26	0.05	0.18	0.15	0.59
A20F30	0.01	0.04	0.33	0.51
A20F32	0.24	0.35	0.31	0.55
A21F15	0.52	0.09	0.32	0.60
Mean	**0.19±.21**	**0.16± .26**	**0.24± .16**	**0.54±.08**

4. Discussion and conclusions

The above results indicated that the processes of AF termination were in agreement to the procedure of treatment. This result was made possible by the clean local characteristic electrical activities. That is the Laplacian estimation procedure significantly enhanced the local activity and suppressed adjacent interfering signals. The methodology demonstrated extracted and provided valuable information for AF studies.

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