Evaluation of the Multiple Frequency Distribution of Conduction Block in Atrial Fibrillation

WC Hu[+], JCF Lai[+], LY Shyu[+], CT Tai[*], T Kao[#]

[+] Dep. of Biomedical Engineering, Chug Yuan University, Chung Li, Taiwan, ROC
[*] Taipei Veterans General Hospital, Taipei, Taiwan, ROC
[#] Dept. of Biomedical Engineering, Yang Ming University, Taipei, Taiwan, ROC

Abstract

A software program has been developed to evaluate the relationship between functional reentry (multiple frequency distribution) and conduction block (slow conduction velocity) in atria fibrillation (AF). This methodology improvement was designed to extract the activation time of AF automatically, calculate the mean cycle length for each record, evaluate conduction velocity, and analyze the frequency distribution by the Short Time Fourier transform (STFT) for studying the spatial relationship between electrical reentry and the conduction block. The electric potential of eight canines with electrically-induced AF were recorded using unipolar electrode 15×8 mapping array on the right atrium epicardium. These data were used in the reconstruction of isochronal map, the mapping of excitation delay, and the mapping of functional reentry for every cycling time. The data indicated that the electrical activation was "stopped" by the block band. The screening of multi-frequency channels at the same cycling time shown in functional reentry mapping has illustrated that the iso-velocity contour was enveloped by a collection of channels with multiple-frequency distribution.

1. Introduction

It was commonly thought that one type of Atria fibrillation (AF) was caused by a self-sustaining arrhythmia [1]. The cause and the treatment procedure were different from the focal discharge. This type of atria fibrillation is caused by functional reentry circuits of activation pathway. The frequency distribution of reentry signal exhibited multi-frequency distribution [2-6]. The cause of reentry is thought to be the block of normal sinus activation wavelets [7]. It would delay and divert the electrical propagation in part of atrium. And, the delayed conduction wavelets would rotate around the excitable tissue. Thus, the block of activation wavelets would be speedup the electrical excitation wavelets at local area. Therefore, the frequency distribution of recorded signal from reentry area should be different from the conduction delayed area.

In AF, the event might have happened at several areas in atrium that caused multiple activations in same cycling time [8]. However, the spatial and temporal relationship between excitation propagation delay and reentry remains unclear. We hypothesized that it would be possible to elaborate the causes of the AF termination through establishing the spatial and temporal relationship between the frequency distribution of reentry and conduction delay. Thus, the objective of this study will be focusing on the development of methodology for extraction of spatial and temporal relationship for conduction delay and reentry. Therefore, a self-developed software program was designed and will be analyzing multi-array electrical potential recording in time domain as well as in frequency domain.

2. Method

The multiple channels of electrical potential of eight canines with electrically-induced AF were recorded using unipolar electrode of 15 by 8 mapping array on the right atrium epicardium. The successful recordings were including sinus period of 8 records, induced AF period of 40 records and AF termination period of 8 records. The sampling rate of these recording was 1000 per second. Every recording was 10 seconds worth.

The reported Tool for Electrical Potential Study (TEPS) software program was developed with Boland C++ builder on P-III computer under XP operating system. The purpose of this processing software was to help researcher analyze epical electrical potential mapping in time domain as well as in frequency domain. The analyzed results presented in spatial mapping and temporary sequence will help researchers correlate multiple dimensional data into one integrated thought.

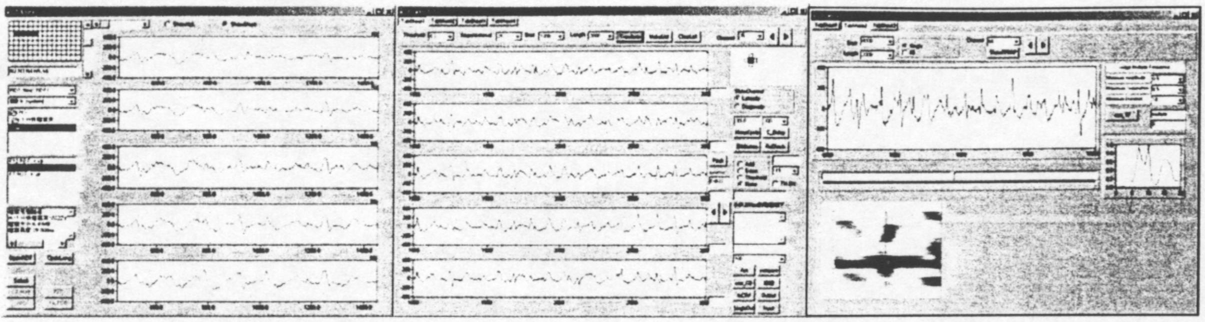

Figure 1: An illustration of user interfacing of self-developed program. In this figure, the inspection of recording signal was shown at left panel. The analysis of conduction block was shown at center panel. And, the user interface of the processes for multi-frequency analysis was to identify reentry as shown at right panel.

The self-developed software program first processed the recorded electrical potential to remove the AC power line noise with notch filter and minimized the DC drift with a high-pass filter. Then, the algorithm of the syntactic analyzer criteria (peak-slope feature matching processes [9]) was used to screen and to mark the activation time automatically for every channel. These extracted data of activation time are used in the reconstruction into isochronal map. The time of activation was tabulated and stored for later analysis. The cycling time was calculated from the difference between the activation. The mean cycle length was calculated for each record.

The user interfacing was shown as Figure 1. In this figure, the software tool for inspecting the recorded signal was shown at left panel. The analysis tools that setting parameters for calculation of conduction velocity was shown at center panel. And, the user interfaces of parameters specification for processes of multi-frequency analysis were to identify functional reentry as shown at right panel.

The conduction velocity of selected channel was evaluated with respecting to 8 adjacent electrodes under user instruction. With the 3 millimeters (mm) electrode spacing, if the 4 electrodes of which conduction velocity were slower than 10 cm/second (conduction time between two electrodes greater than 30 ms), the evaluating electrode would be marked as conduction block. These analyzed results were presented as map of conduction block.

The same recorded electrical potential was also processed with the Short Time Fourier transform (STFT) to establish the frequency distribution using 1024 milliseconds (ms) windowing and with increment every 8 ms. As shown in Figure 2, This figure was demonstrating the processing step and the criteria for identifying functional reentry using STFT. At the top panel, A, it was one of the original recorded signals. At panel B, it was the display of enlarged selected segment. At panel C, it was 8 ms worth of frequency distribution

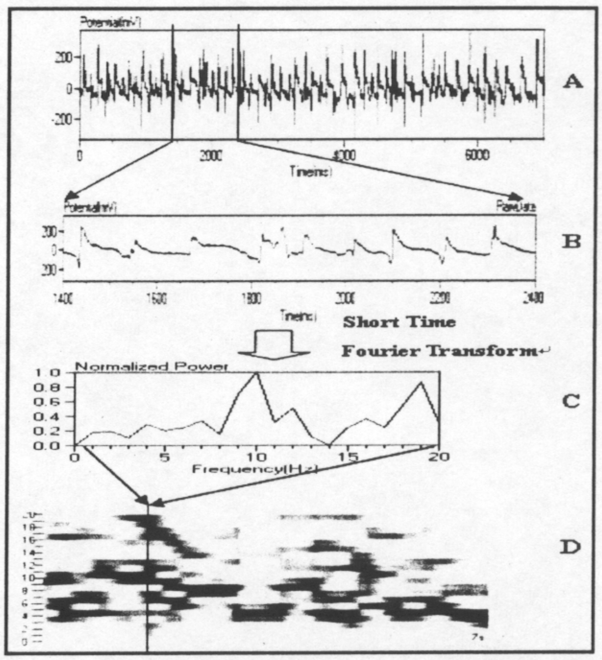

Figure 2: A demonstration of STFT processing step. At the top panel A, it was one of the original recorded signals. At panel B, it was the display of enlarged selected segment. At panel C, it was 8 ms worth of frequency distribution extracted from Panel D, the display of STFT analysis from the selected segment data.

extracted from Panel D, the display of STFT analysis from the selected segment data. the marking of functional reentry was using criteria of the amplitude as threshold, the separation of peak frequency as feature of functional reentry [2]. The extracted marking of multiple-frequency was reconstructed into a map of functional reentry.

The TEPS system was designed to store the processing procedure used and extracted activation time marker. The extracted activation time markers were used to reconstruct the mapping of isochronal, the mapping of

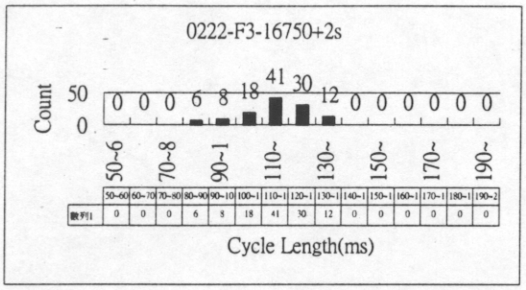

Figure 3. The tally of cycling time distribution of two seconds in AF. This data demonstrated that the peak cycling time of 41 counts was at 110 to 120 ms.

the conduction block (mapping of marked conduction velocity), and the mapping of functional reentry (mapping of marked multi-frequency distribution) for every cycling time. Three reconstructed mappings and their sequence of events were stored and could be replayed.

3. Result and Discussion

The TEPS (self developed program) was first used the extracted activation time to tally the distribution of cycling time for statistically determination for the accuracy of extracted activation time, as shown in figure 3. This figure was showing a typical (recording 0222-F3 starting from 16750 and 2 second worth) distribution of the cycling length in AF. The peak of distribution of the cycling length was at 110 millisecond (ms) with the count of 41. The average cycling time of electrically-induced AF from 8 canines, 120 channels each, and with 24 recordings (240 seconds worth of AF data) was 130±14.83ms.

The mapping of isochronal, conduction block and functional reentry were complied and were illustrating in Figure 4 using cycling length as time marker. This figure was illustrating four consecutive cycling times of the reconstructed maps with the isochronal mapping at center, the conduction block mapping at left, and, the mapping of multi-frequency distribution at right.

The shade of gray in isochronal map was representing the time difference of activation time. The light shade of gray was showing shorter time difference to the set marker. The darker shade of gray was representing the longer time difference to the set marker.

The black marks in the conduction block (left panel) and functional reentry map (right panel) were illustrating of which elected electrode was meeting the criteria. The map of conduction block reconstructed from each channel can be grouped into a iso-velocity contour which was shown in Figure 4 at left panel.

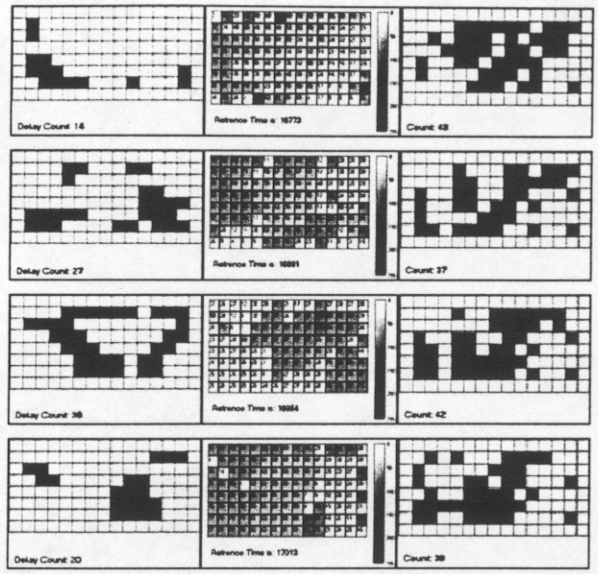

Figure 4. An illustration of 4 consecutive cycling time of reconstructed mappings with the isochronal mapping at center, the conduction block mapping at left, and, the mapping of multi-frequency distribution at right. In this figure, using isochronal mapping as reference, the marking of conduction block were holding up the progression of reentry.

Observing the map of conduction block (left panel) with reference to isochronal map (center panel), the marking on the map of conduction block was pointing up the significant time difference area in the isochronal map.

At the same cycling time, the multiple frequency analysis using STFT was reconstructed into functional reentry map (right panel). With reference to the isochronal mapping (center panel) and conduction block map (left panel), these data were showing that the electrical activation was "stopped" by the band of conduction block. Again, using isochronal mapping as reference, the marking of conduction block were holding up the progression of reentry.

As illustrated in the Figure 4, the collection of channels with functional reentry map (the electrodes met the multiple-frequency distribution criteria) was enveloped by a contour of conduction block (iso-velocity channel). This result was particularly elaborated in the activation 3 of Figure 4. In this activation, the conduction block was encircling the multiple frequencies channel. This meant that there were two distinctive electrical potential activities in AF. One activity is prolonging the conduction velocity and delay the activation. The other type was self-sustained depolarization and regeneration. The number of electrode marked with the conduction block and functional reentry were recorded and tally along with the cycling time. The statistical calculation was shown in Table 1. The data in this table was

Table 1: The comparison the number of electrode marked as Conduction Block and Functional Reentry. The data in this table was grouped into 4 events that labeled as 1 to 4. The label 1 was the initial state into AF and the label 4 was the event toward the termination of AF. This data has shown that there is no difference in number of electrode marked as conduction block or functional reentry. However, this data has also indicated that the number of electrode marked with conduction block or functional reentry were decreasing toward the termination of AF

	Conduction Block	**Functional reentry**
Group	**Mean ± Std**	**Mean ± Std**
1	**32.33±14.91**	**32.72±18.27**
2	**31.14±13.99**	**33.5±18.80**
3	**31.52±15.48**	**33.39±13.84**
4	**25.09±14.01**	**23.95±13.71**

grouped into 4 events that labeled as 1 to 4. The label 1 was the initial state into AF and the label 4 was the event toward the termination of AF. This data has shown that there is no difference in number of electrode marked as conduction block or functional reentry. However, this data has also indicated that the number of electrode marked with conduction block or functional reentry were decreasing toward the termination of AF. Furthermore, from the observation of extracted data toward the termination of AF, there is a trend that the area or channels occupied by the conduction block were dramatic integrated into few big cluster. And, the area or channels of reentry were disintegrated into several small clusters. This observation can be summarized that increasing the area of conduction block will terminate the AF.

4. Conclusion

In conclusion, we have reported a self-developed software program that can be used to screen electrical activation pathway in time domain as well as in frequency domain. The extracted data are reconstructed into the mapping of conduction block and the mapping of multi-frequency (reentry) for each cycling time. In this way, the properties of conduction block can be evaluated in detail. The relationship of conduction velocity and its frequency distribution can be established.

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Reference

1. Moe G.K., Abildskov J.A., "Atrial fibrillation as a self-sustaining arrhythmia independent of focal discharge", Am Heart J, vol.58, pp.59-70, 1959
2. Evans F.G., Rogers J.M., Smith W.M., "Automatic Detection of Conduction Block Based On Time-Frequency Analysis of Unipolar Electrograms", IEEE Transaction on Biomedical Engineering, vol. 46, pp.1090-1097, September, 1999
3. Sih H.J., Sahakian A.V., Arentzen C.E., Swiryn S., "A Frequency Domain Analysis of Spatial Organization of Epicardial Maps", IEEE Transaction on Biomedical Engineering, vol.42, pp.718-727, JULY, 1999
4. Lovett E.G., Ropella K.M., "Time-Frequency Coherence Analysis of Atrial Fibrillation Termination During Procainamide Administration", Annals of Biomedical Engineeing, vol.25, pp.975-984, 1997
5. Stridh M., Sornmo L., Meurling C.J., Olsson S.B.," Time-Frequency Characterization of Atrial Arrhythmias Using Principal Component Analysis", Proc. IEEE Conf. Eng. In Medicine and Biology, pp.25-28, October, 2001
6. Shenasa M., Borggrefe M., Breithard G., "Spiral waves as a mechanism of reentrant excitation in isolated cardiac muscle. In Cardiac Mapping" Mount Kisco, NY: Futura Pub Co., pp.607-623, 1993
7. de Groot, Natasja M.S., Allessie, Maurits A., "Mapping of atrial Fibrillation", Ann. 1st Super. Sanita, Vol., 37, #3, pp. 383-392, 2001.
8. Moe G.K. , "On the multiple wavelet hypothesis of atrial fibrillation", Arch. Int Pharmacodyn, vol.140, pp.183-188, 1962
9. Simpson E.V., Ideker R.E., Smith W.M., "Evaluation of an Automatic Cardiac Activation Detector for Bipolar Electrograms", Med & Biol. Eng. & Comput., vol.31, pp.118-128, 1993

Address for correspondence:

Weichih Hu, Ph.D.; Associate Professor
Dept. of Biomedical Engineering;
Chung Yuan University
#22, Pu-Jeng, Pu-Chung Li,
Chung Li, Taiwan, ROC, 32023
Phone: 886-3-2654512
Fax: 886-3-2654599
Email: weichih@mail.be.cycu.edu.tw