Prediction of Paroxysmal Atrial Fibrillation by Footprint Analysis

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Abstract

This study presents a simple algorithm named footprint analysis to predict risk and onset of paroxysmal atrial fibrillation (PAF) from single channel surface electrocardiogram. The approach is based on hypothesis that subject who has risk of PAF would display a specific pattern in change of heart rate and could be applied as a predictor to identify the risk and onset of PAF. To quantify patterns of heart rate dynamics, the triplet codes (0,1,2) is assigned according to difference of adjacent R-R intervals to represent equal, acceleration, and deceleration of successive RR intervals, respectively. A R-R interval series is then continuously weighted by a 7 heartbeats window, which results in a set of 6-bits number. Each number represents a specific pattern of heart rate dynamics. The strategies for both events of competition are to determine which number has higher possibility to be present in PAF patients, and to identify the number that only present before onset of PAF. A set of number determined by the algorithm from learning dataset was then applied as footprint to the testing dataset. Score for event 1 was 33/50 (entry 20010422.030701) and score for event 2 was 38/50 (CinC Challenge 2001 entry 20010423.045638, entrant 2). The successful of this algorithm is to find hidden pattern embedded in the highly dimensional phase space of R-R intervals. We look forward to understanding the link between microscopic variation in R-R intervals and macroscopic physiologic conditions

1. Introduction

Paroxysmal atrial fibrillation (PAF) is a major cardiac arrhythmia characterized by extremely irregular rhythm, unstable hemodynamics and risk of thromboembolic events. Therefore, it is important to develop a reliable predictor of acute onset of PAF because of possible benefits from preventing it by defibrillation, drug treatment and anti-tachycardia pacing technique. Several reports showed that twelve-lead electrocardiograms [1], signal-averaged P-wave morphology [2,3], R-R interval dynamics [4,5], and atrial ectopy [5,6] may be possible predictors of the onset of PAF. However, these non-invasive detections have not been proved to be reliable and their sensitivity and specificity still need further evaluation.

The goal of Computers in Cardiology Challenge 2001 is to develop a fully automatic prediction tool, only based on surface electrocardiogram, to identify risk of PAF and predict acute onset of PAF events. The database provided by the challenge consists of two groups from PAF patients and non-PAF subjects. Each group has 25 subjects and each subject has two half hour recordings of electrocardiogram. For PAF group, one is prior to onset of PAF and the other is far away from that within 45 minutes. For control group, no PAF events occur in each subject. There are another 50 unknown subjects for evaluate which subjects has risk of PAF and which recording may directly follow by onset of PAF.

2. Method

We propose a symbolic dynamics approach, called Footprint analysis, to investigate heart rate dynamics. Consider an R-R intervals time series: {RR_0, RR_1, RR_2, RR_3, RR_4, ……, RR_n}. For each pair of successive beats, we can classify it into one of the 3 states that represent increase in RR, decrease in RR, and no change in RR (Fig 1A). These 3 states are mapped to the symbols 0, 1, and 2 (see Eq. E.1 for an example of mapping rule). Note that a decision has to be made regarding the range of difference for two successive RRs to be considered as equal. Here we show the case defining the range of equal as fifty milliseconds.

$$w_n(RR_n, RR_{n+1}) = \begin{cases} 0 : |RR_{n+1} - RR_n| <= 50\ \text{ms} \\ 1 : RR_{n+1} - RR_n < -50\ \text{ms} \\ 2 : RR_{n+1} - RR_n > 50\ \text{ms} \end{cases} \quad \text{(E.1)}$$

In this case, two successive RR intervals are considered equal if their difference is smaller then 50 milliseconds (a symbol 0 will be assigned to this pair of successive RR).

In this study, we map each 7 successive interbeat intervals to a 6-tuple (a sequence of symbols of length 6). For every 7 interbeat intervals, there is a corresponding 6-tuple sequence. For further simplification, each 6-tuple can be mapped to a unique integer number (between 0 and 3^6-1) with the following rule:

$$S_n = \overrightarrow{W_n} \bullet \overrightarrow{I}$$

$$\begin{cases} \overrightarrow{W_n} = (w_n, w_{n+1}, w_{n+2}, w_{n+3}, w_{n+4}, w_{n+5}) \\ \vec{I} = (3^0, 3^1, 3^2, 3^3, 3^4, 3^5) \end{cases}$$

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(E.2)

where the vector W represents a 6-tuplet, and I is a weighting function which guarantees the inverse mapping is also valid. The number S, therefore, represents a unique combination of specific pattern of heart rate variations. By carrying out this procedure on all R-R intervals, our algorithm produces a set of 6-tuple that can be mapped to integer numbers (Fig 1B). A histogram (Fig 1C) of these numbers can be obtained to evaluate repetitive patterns of heart rate dynamics for subjects in different groups.

The algorithm can be utilized in PAF risk assessment as well as for predicting onset of PAF. For risk assessment, we examine the histograms generated from PAF group and control group. The strategy is to determine what numbers have significantly higher probability to occur in PAF patients than in control group subjects. Numbers that have greater probability to occur in PAF database represent the pathological rhythm that are more likely to be found in hearbeats of PAF patient. Therefore, the difference in histograms of PAF group and control group can be used to assess which subject may experience PAF. Furthermore, we used the Receiver Operating Characteristics (ROC) curve to test the best cut-off level of frequency (of histogram) in order to select best numbers as predictors.

For predicting onset of PAF, the strategy is similar, i.e., to find the set of numbers that occur more prior to the onset of PAF. These numbers can be used as predictors to tell if patient will have higher probability to have PAF in the immediate future.

3. Result

3.1. Event 1: PAF risk assessment

To identify which subject experienced PAF, we

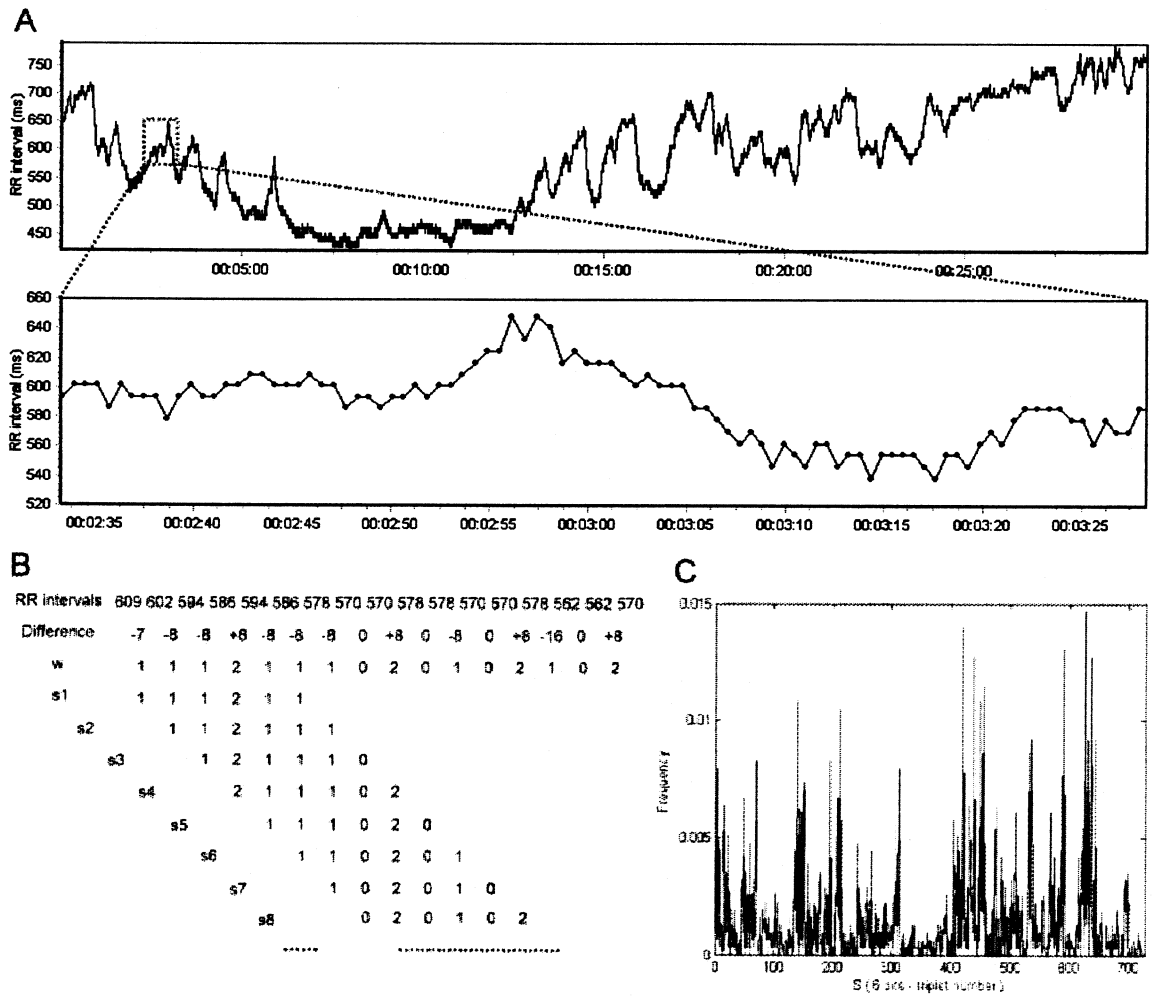

Fig 1. Panel A shows a 30 minutes tracing of RR intervals following a magnification of 1 minute of period in the lower panel. Heart rate dynamics is simplified as 3 states (equal, acceleration, and deceleration). Panel B shows mapping procedure using a window of 6 pairs of successive RR intervals applied continuously to 30 minutes heart rate tracing. Panel C shows histogram of these numbers obtained from B as frequency distribution.

analyze interbeat intervals of each group by footprint analysis. Fig 2A shows the difference of frequency distributions between PAF and control group. Here we employed the receiver operating characteristics (ROC) curve (Fig 2B) to evaluate the best cut-off level and determine which number can be applied as a predictor to assess the risk of PAF. The optimal cut-off frequency is 0.06 with sensitivity of 0.72 and specificity of 0.76.

3.2. Event 2: PAF prediction

To identify which recording directly followed by PAF, we analyzed pairs of last 10 minutes R-R interval of PAF subjects. One is far from PAF event and the other is followed by PAF. Fig 2C compares difference of frequency of each number. Positive value means higher probability of certain number occurring prior to onset of PAF. Here we evaluate sensitivity only (Fig 2D) to determine the best cut-off level. The optimal cut-off frequency is 0.003 with sensitivity of 0.76.

4. Discussion

The symbolic approach has been studied in language and DNA sequence analysis. However, there is no current report using symbolic tool to study heart rate variability. The present study provides both an important first step and a simple tool for predicting PAF using symbolic dynamics. In terms of conventional tools such as power spectrums, cardiac arrhythmias will disturb the spectrum and must be removed or averaged from RR signals before doing fourier transformation. However, smoothening procedure may lead to overlook underline pathologic cardiac condition and consequently limit its ability to

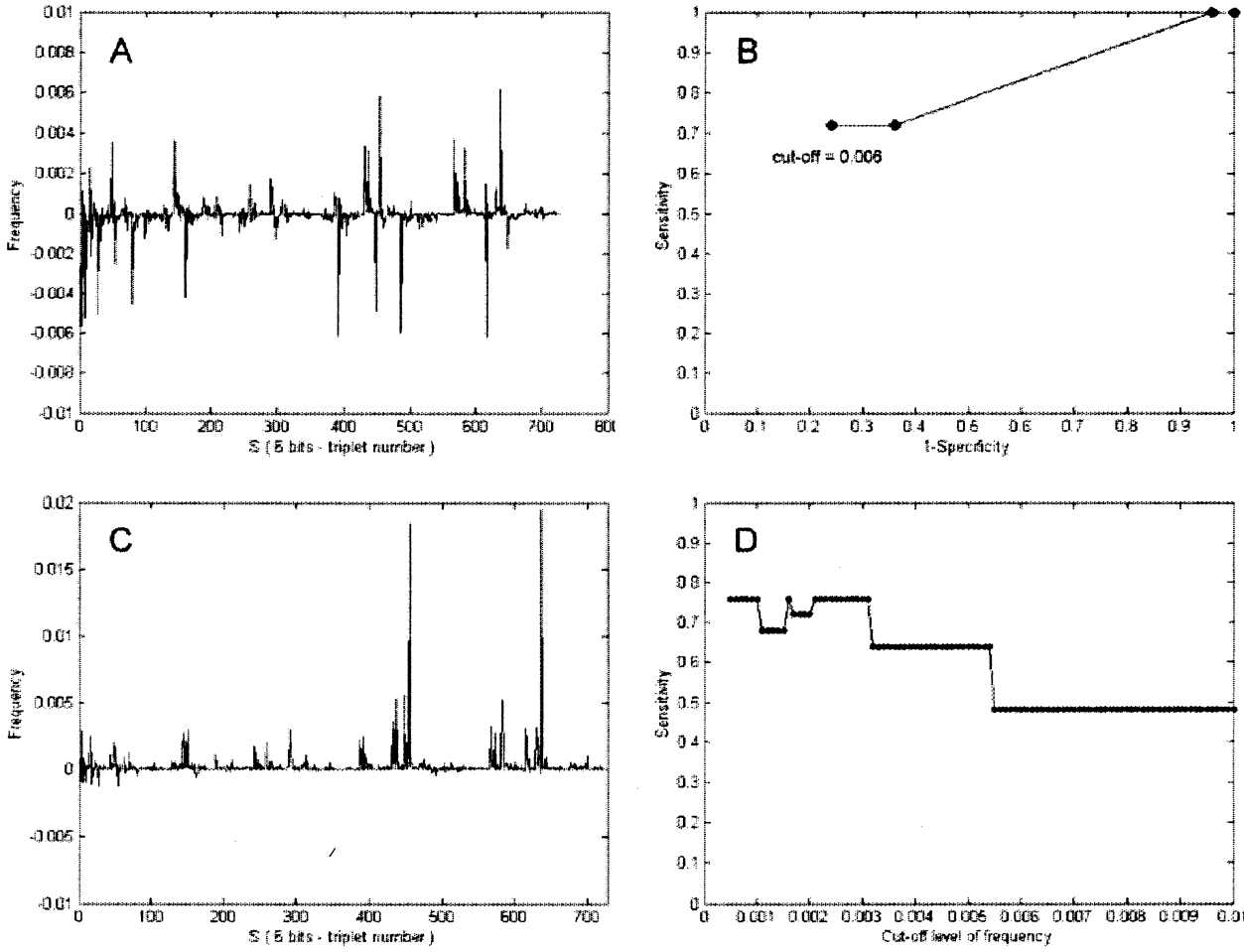

Figure 2. Panel A and B are for event 1; Panel C and D are for event 2. Panel A shows differences of frequency of each number obtained from PAF and control group. The positive value means higher probability of certain number to occur in PAF subjects. The strategy is to determine the cut-off frequency. Panel B shows receiver operating characteristics (ROC) curve with best cut-off frequency of 0.006 which has sensitivity of 0.72 and specificity of 0.76. Panel C compares differences of frequency distribution between recordings prior to onset of PAF and far away from any PAF events. Panel D shows best sensitivity at cut-off frequency of 0.003 which has sensitivity of 0.76.

clinical practice with cardiac arrhythmias. This study presents a symbolic approach to classify heart rate as few states such as equal, acceleration and deceleration. By adjusting the range of difference of RR intervals considering equal, we can define a specific probe to detect certain cardiac rhythm disturbance only occur in PAF patients. In the further study, we look forward to investigate the quantification of symbolic mapping and applied it to other clinical conditions.

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References

[1] Dilaveris PE, Gialafos, EJ, Sideris SK, Theopistou AM, Andrikopoulos GK, Kyriakidis M, Gialafos JE, Toutouzas PK. Simple electrocardiographic markers for the prediction of paroxysmal idiopathic atrial fibrillation. Am Heart J 1998;135:733-738.

[2] Ishimoto N, Ito M, Kinoshita M. Signal-averaged P-wave abnormalities and atrial size in patients with and without idiopathic paroxysmal atrial fibrillation. Am Heart J 2000;139:684-689.

[3] Amar D, Roistacher N, Zhang H, Baum MS, Ginsburg I, Steinberg JS. Signal-averaged P-wave duration does not predict atrial fibrillation after thoracic surgery. Anesthesiology 1999;91:16-23.

[4] Vikman S, Makikallio TH, Yli-Mayry S, Pikkujamsa S, Koivisto AM, Reinikainen P, Airaksinen KEJ, Huikuri HV. Altered complexity and correlation properties of R-R interval dynamics before the spontaneous onset of paroxysmal atrial fibrillation. Circulation 1999;100:2079-2084.

[5] Hnatkova K, Waktare JEP, Murgatroyd FD, Guo X, Baiyan X, Camm AJ, Malik M. Analysis of the cardiac rhythm preceding episodes of paroxysmal atrial fibrillation. Am Heart J 1998;135:1010-1019.

[6] Kolb C, Nurnberger S, Ndrepepa G, Schreieck J, Zrenner B, Karch M, Schmitt C. Modes of initiation of paroxysmal atrial fibrillation an analysis of 157 spontaneously occurring episodes using 12-lead Holter monitoring. PACE 2000;23(4):607.

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