Prediction of Spontaneous Termination of Atrial Fibrillation in Surface ECG by Frequency Analysis

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Abstract

We developed an automatic algorithm for predicting the spontaneous termination of atrial fibrillation (AF) using the 2004 PhysioNet / Computers in Cardiology Challenge database. The algorithm consisted of QRST subtraction to cancel ventricular and correlated activity followed by peak frequency analysis on the remainder signal. A learning set was used to determine a 5.9 Hz peak frequency threshold to separate immediately terminating (T) from non-terminating (N) segments. To separate T from non-immediately terminating (S) segments, the frequency analysis was preceded by QRST morphology matching to identify pairs of S and T segments from each individual patient. Higher frequency segments were labeled as N or S respectively. This algorithm correctly separated 19/20 T vs. N segments from 20 different patients and 18/20 segments in 10 patients in the learning set and correctly identified 25/30 segments from Test Set A and 16/20 segments from Test Set B.

1. Introduction

Atrial fibrillation (AF) is the most common arrhythmia affecting more than two million people in the US alone. Its prevalence increases with age and it is estimated to be present in 5% of those older than age 65, and 10% of those older than 70 [1]. The risk of sustained AF is associated with stroke and myocardial infarction, as well as mortality, fatigue, and heart failure [1, 2]. There is evidence that spontaneous terminating (paroxysmal) AF is a precursor to the development of sustained AF.

Most often, spontaneous terminating episodes of AF are very short; however, longer episodes lasting for several minutes also occur. Slight changes in rhythm may be used to predict termination of AF. This can further our understanding of the mechanisms of spontaneous termination of AF and potentially identify new treatments for sustained AF.

Frequency domain analysis has been used in the surface ECG to characterize atrial fibrillation after QRST cancellation [3] and this cancellation is known to be a reliable process to characterize AF signals [4]. In addition, sustained AF signal characteristics have been shown to be reproducible for up to 24 hours in clinically stable patients [5].

Based on the theory of electrophysiologic remodeling of AF [6] that suggests that AF tends to be self supporting and of higher rate when sustained, we hypothesized that 1) AF episodes with higher frequencies would be less likely to self-terminate while those with lower frequencies would be more likely to self-terminate, and 2) terminating episodes could be differentiated from the sustaining episodes based on the frequency of the AF signals.

2. Methods

2.1. PhysioNet Database

For this study we used data from the "Spontaneous Termination of Atrial Fibrillation: A challenge from PhysioNet and Computers in Cardiology 2004" database [7]. This database is composed of 80 surface ECG recordings belonging to three different groups:

1. Group N: non-terminating AF not observed to have terminated for the duration of the long-term recording, at least an hour following the segment.

2. Group S: AF that terminates 1 min after the end of the recording.

3. Group T: AF that terminates immediately (within 1s) after the end of the recording. These records come from the same long-term ECG recordings and immediately follow those in Group S.

The data is further divided into a learning set which consists of 10 labeled records from each of the N, S and T groups and two test sets. Test Set A contains 30 records of which about half are from Group N and the remainder are from Group T. Test Set B contains 20 records, 10 from each of groups S and T.

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2.2. Cancellation and frequency analysis

To study the AF characteristics from the surface ECG signals, we used a QRST cancellation method described in [4].

The surface ECG signals were band pass filtered between 1 and 50 Hz and periods with significant noise or containing sinus rhythm were not used for further analysis.

In order to obtain a good median beat for QRST cancellation, each 1 min long ECG segment was dissected into 6 contiguous 10 sec ECG sub-segments.

For each ECG sub-segment, fiducial points were detected [8] and all complexes were aligned to generate a median beat. The median beat was then aligned at each fiducial point and subtracted from the ECG to obtain the remainder ECG.

Fourier analysis was used to calculate the peak frequency in the 3-9 Hz band of each 10 sec sub-segment and the average value of the 6 contiguous sub-segments was obtained and assigned as the peak frequency for that ECG segment.

An example of this process is shown in Figure 1.

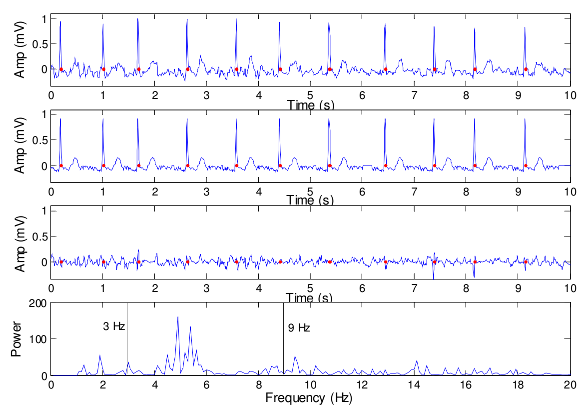

Figure 1. An example of QRST cancellation. From top to bottom: AF ECG signal with fiducial points marked, median beat train aligned at each fiducial point, remainder ECG, and power spectrum of the remainder ECG (3 to 9 Hz band is marked with vertical lines).

2.3. Template matching

Since ECG signals from groups S and T in Test Set B are contiguous and from the same patients, we used a template matching method to find corresponding pairs.

A median beat was obtained for each segment via the method described in section 2.2 and a correlation coefficient was calculated for every two median beats from the different ECG segments. The two median beats that produced the highest correlation coefficient were considered to be from the same patient. Figure 2 shows two examples of matching beats from different segments.

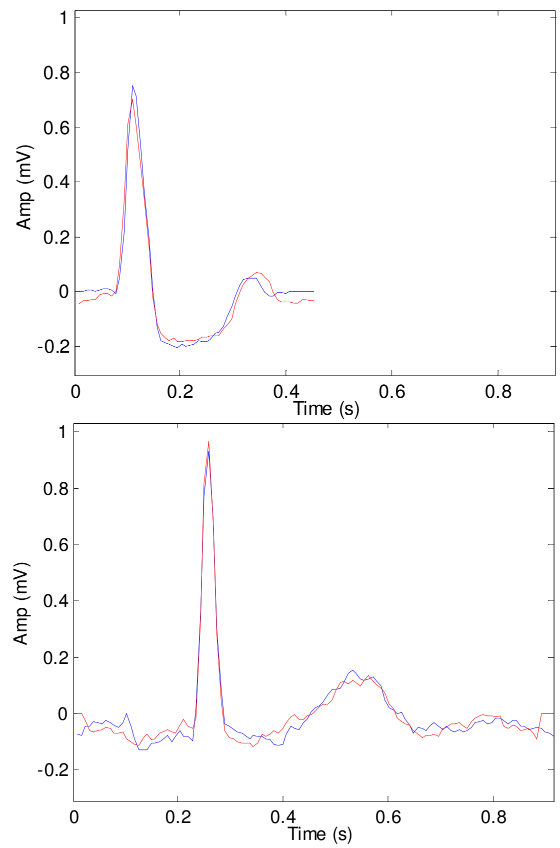

Figure 2. Examples of template matching median beats. Top: B12 & B20. Bottom: B10 & B15. Note that QRST complex durations are different due to different intrinsic rates.

3. Results

3.1. Learning set

We used the learning set to characterize the peak frequency on each of the 10 ECG segments in groups N, S and T as shown in Figure 3.

The ECGs in Groups N had overall higher peak frequencies than T. Using a 5.9 Hz threshold, we could correctly separate 19/20 N vs. T segments. In addition, we noted that most S segments had slightly higher peak frequencies than T segments, and using this criterion, we could separate 18/20 segments.

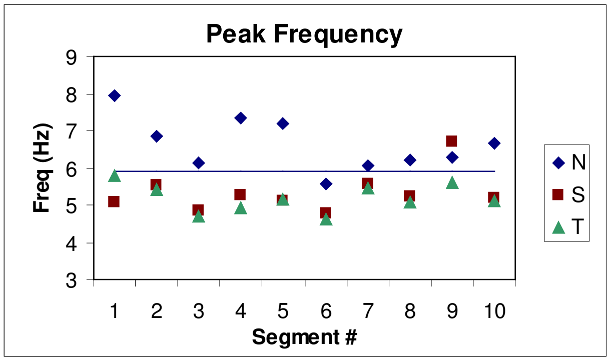

Figure 3. Peak frequencies of the learning set. The X-axis shows each of the 10 ECGs in each group and the Y-axis shows the peak frequency of each ECG segment. The horizontal line marks the 5.9 Hz threshold used for classification.

3.2. Test Set A

We applied the same peak frequency analysis and frequency threshold to the segments from Test Set A and correctly identified 25/30 segments as shown in Table 1 and Figure 4.

ECG	Group	ECG	Group
a01	N	a16	N
a02	T	a17	N
a03	T	a18	T
a04	N	a19	N
a05	N	a20	N
a06	T	a21	T
a07	N	a22	N
a08	N	a23	T
a09	T	a24	T
a10	T	a25	T
a11	T	a26	N
a12	T	a27	T
a13	T	a28	N
a14	T	a29	N
a15	N	a30	N

Table 1. Test Set A results. Non-terminating (N) vs. immediately terminating (T) segments.

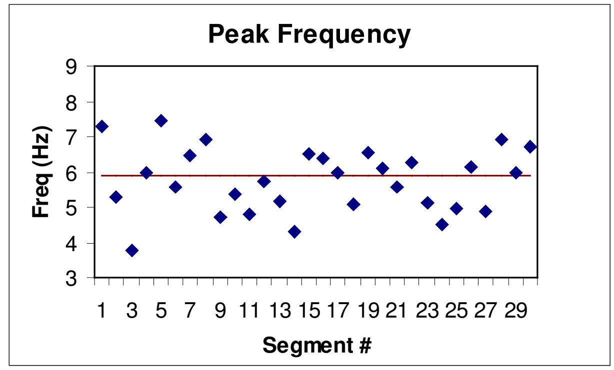

Figure 4. Peak frequency of 30 ECG segments in Test Set A. ECGs with frequency above the 5.9 Hz cutoff were labeled as non terminating (N), and those below as immediately terminating (T).

3.3. Test Set B

We applied the template matching method to the Test Set B segments to find corresponding S and T ECG pairs from each patient, and then applied the peak frequency analysis to each of the 10 pairs of ECGs to identify which segment had higher peak frequencies. Higher frequency segments were scored as non-immediately terminating segments (S) and lower peak frequencies segments as immediately terminating segments (T).

The peak frequencies of each S and T pairs are shown in Table 2 and Figure 5. We correctly identified 16/20 segments.

ECG pair	ECG	Group	ECG	Group
1	b01	S	b03	T
2	b02	S	b07	T
3	b04	S	b13	T
4	b05	S	b19	T
5	b06	S	b17	T
6	b09	S	b08	T
7	b10	S	b15	T
8	b11	S	b18	T
9	b12	S	b20	T
10	b14	S	b16	T

Table 2. Test Set B results. Paired segments with non-immediately terminating (S) and immediately terminating (T) segments.

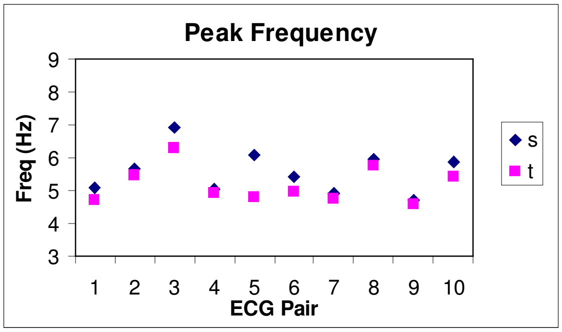

Figure 5. Peak frequency of the 10 ECG pairs in Test Set B. Higher peak frequency segments were classified as non-immediately terminating (S), while those with lower peak frequencies were classified as immediately terminating (T).

4. Discussion and conclusions

Atrial fibrillatory peak frequency was demonstrated to be capable of predicting the spontaneous termination of AF. These results support our hypothesis that AF episodes with lower peak frequencies are more likely to self-terminate, while those that have higher peak frequencies are more likely to sustain. This technique may help further our understanding of the mechanisms of termination of AF and therapies to manage it by providing a non-invasive method that can be used to continuously assess the status of the arrhythmia.

However, the algorithm performance was not optimal. First, a single threshold was used to evaluate the overall population and there may be patient specific conditions (e.g. pharmacologic or pathophyisologic) that shift the peak frequency of the AF segments, whether sustaining or not, above or below this threshold. Also, in some cases, very fine fibrillatory waves lowered the signal to noise ratio and undermined the performance of the algorithm.

In this study we demonstrated that we could discriminate non-terminating vs. immediately-terminating segments, and non-immediately terminating vs. immediately-terminating AF segments by performing peak frequency analysis of the remainder ECG signal. This provides a simple method to characterize AF and may provide new treatment options as well.

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