Analysis of RR Interval and Fibrillation Frequency and Amplitude for Predicting Spontaneous Termination of Atrial Fibrillation

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Abstract

We assessed characteristics of atrial and ventricular activity from the ECG for predicting the offset of atrial fibrillation for the 2004 PhysioNet/Computers in Cardiology Challenge. Seven parameters were analysed with five based on the statistical characteristics of the RR interval (mean, standard deviation, skewness, kurtosis and median beat-to-beat change), and fibrillation frequency and atrial signal amplitude. The power of the parameters to predict termination of the arrhythmia was assessed individually and in combination using linear discriminant analysis (LDA) and artificial neural network (ANN) techniques. Fibrillation frequency with a threshold value of 5.55 Hz was able to identify 10/10 learning set records which terminated immediately (T) and 8/10 of non-terminating records (N) and was the best of the individual parameters. Classifications for the test set for event 1 of the challenge for algorithms based on fibrillation frequency alone, LDA and ANN received scores of 24/30, 18/30 and 23/30 respectively. Low fibrillation frequency is an indicator of spontaneous termination of atrial fibrillation.

1. Introduction

Atrial fibrillation (AF) is classified according to the treatability of the condition: permanent, persistent or paroxysmal [1]. Paroxysmal AF is by definition self terminating and may be the precursor to sustained or persistent forms of the condition. AF is characterised by rapidly beating atria which can often be seen on the ECG as a variable amplitude oscillatory baseline (figure 1). Some treatments of AF, including ablation therapy and drug cardioversion are known to organise the fibrillatory waveform prior to restoration of sinus rhythm. This may be indicative of a reduced number of re-entrant waves sustaining the arrhythmia. In AF the frequency of oscillation is in the range 3 to 10 Hz and drugs having an anti-arrhythmic effect on AF are known to slow the frequency [2]. Also, treatment of AF by ablation therapy is known to progressively reduce the fibrillatory frequency prior to restoration of sinus rhythm in some patients [3]. These suggest that slowing of fibrillatory frequency may be a potential indicator of spontaneous termination of paroxysmal AF. Amplitude changes in the AF waveform are thought to reflect complexity of the underlying fibrillatory waves. It has been observed that under anti-arrhythmic medication the waveform becomes more organised with fewer amplitude changes than otherwise. Hence body surface atrial signal amplitude may also be a potential marker of termination of AF. In AF conduction through the AV node occurs more randomly than in sinus rhythm, leading to large variations in the interval between ventricular beats. Given the hypothesis that termination of AF is preceded by organisation of the atrial rhythm, this may be reflected in more stable ventricular activation which can be measured by the inter-beat spacing or RR interval.

It was our aim to investigate characteristics of both atrial and ventricular activity of the ECG for the prediction of spontaneous offset of paroxysmal AF. Improved knowledge about the conditions under which self termination occurs could give an insight into how current treatments for persistent episodes could be improved. To be able to predict the offset of AF is a step towards understanding the necessary conditions under which termination is possible.

Figure 1. Atrial fibrillation is characterised by oscillatory baseline and variable beat-to-beat interval on the ECG.

2. Methods

2.1. Data

All data for the challenge was supplied by PhysioNet and consisted of simultaneous 2 lead recordings of atrial fibrillation of duration 60 s at intervals of either 60 s (label S) or 1 s before the offset of AF (label T), or from recordings in which AF did not terminate (label N). The timings of QRS complexes were also provided for each recording. The data consisted of a learning set for which the classifications S, T and N were provided. The challenge was to correctly identify those recordings in the test set which terminated immediately and those which did not terminate. A further challenge to distinguish those records terminating immediately from those terminating after one minute was not attempted.

2.2. Analysis of RR interval

Intervals between ventricular beats (RR) were calculated from the QRS timings provided by PhysioNet. Several statistical parameters were calculated from the RR interval data: mean, standard deviation, kurtosis, skewness, and median beat-to-beat change in RR (ΔRR). Figure 2 shows the ECG and associated RR and ΔRR for one subject in the study.

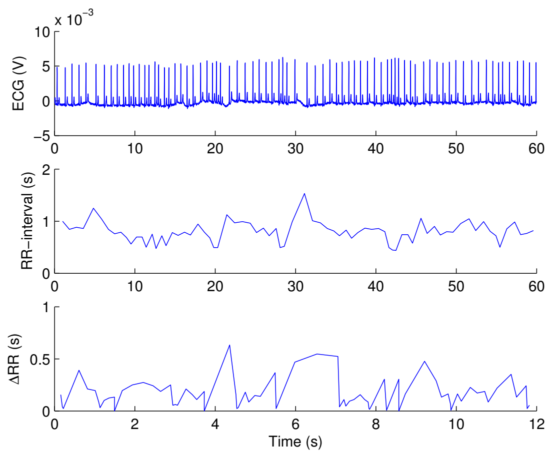

Figure 2. ECG and corresponding RR and ΔRR series.

2.3. Analysis of fibrillation frequency

The power spectrum of the atrial signal obtained after QRST subtraction was calculated by periodogram using Fast Fourier Transform. The peak frequency in the range 3 to 10 Hz was obtained automatically by finding the largest spectral peak in this range. Figure 3 illustrates removal of QRST components by subtraction and the resulting power spectrum for an ECG in this study.

2.4. Analysis of fibrillation amplitude

An estimate of fibrillation amplitude was obtained by filtering the ECG signal with median filter with a sliding 2 s window. The mean amplitude was calculated for each record.

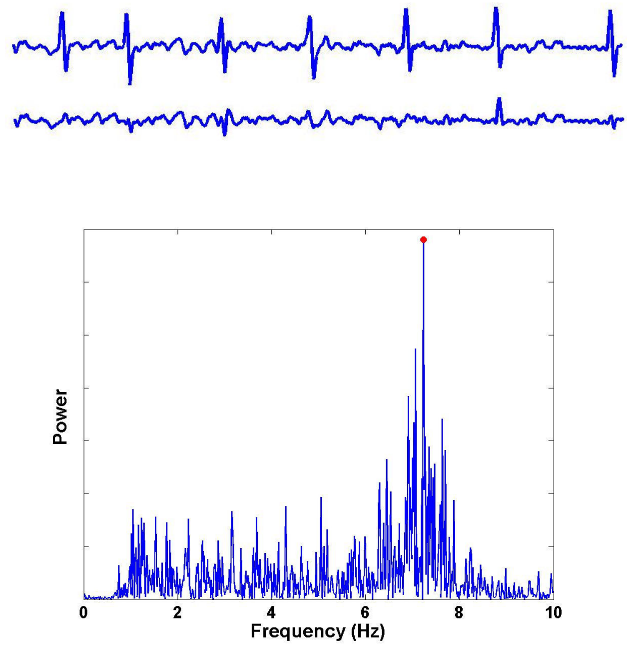

Figure 3. ECG lead (top), residual ECG lead after QRST subtraction and frequency spectrum of residual lead.

2.5. Analysis of combined parameters

Three values for each of the parameters described were calculated for each ECG record: one value calculated from the full ECG record of 60 s, one value for the first 30 s of the record, and one value for the final 30 s of the record. By use of thresholds, each of the parameters was assessed individually for its ability to separate the terminating from the non-terminating ECGs. Changes in the values between first and last 30 s were compared.

Additionally, we investigated combining the parameters using linear discriminant analysis (LDA) and artificial neural network (ANN) algorithms.

2.5.1. Linear discriminant analysis

An LDA model was developed for every combination of 3 individual parameters described above. The area beneath the receiver operating characteristic (ROC) was calculated for each of these models, which is a measure of how well the model fits the data. The parameters to include in the final model were selected from those which gave the largest area under the ROC. The final LDA model contained six variables.

2.5.2. Artificial neural network

The ANN comprised three input neurons, a hidden layer of 10 neurons and a single output neuron, and was trained by back propagation. The mean was removed from the input parameters and variances scaled to 1.0. The ANN was trained for a maximum of 1000 iterations using a 'momentum' tuning parameter of 0.95. Various input data structures were assessed using the learning data set, and three parameters identified which gave good separation of non-terminating and terminating AF groups. The final ANN configuration was tested using 8 repeat sets of training neuron weights to determine the most consistent classification for each test case presented.

3. Results

3.1. Learning set

3.1.1. Individual parameters

AF frequency with a threshold of 5.5 Hz, and ΔRR with a threshold of 0.1 s gave the best results for the individual parameters achieving 7/10 (N) 10/10 (T) and 10/10 (N) and 6/10 (T) correct classification respectively (figure 4).

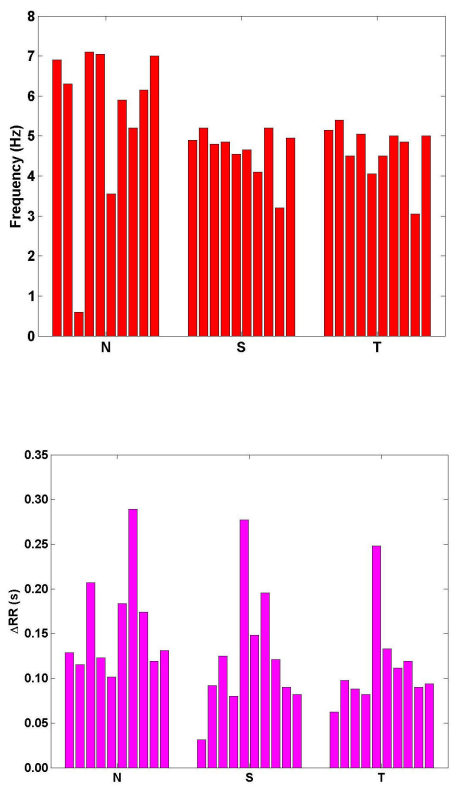

Figure 4. AF frequency and ΔRR for each record in N, S and T groups.

Differences in the parameters calculated from the first and last 30 s of the records were unable to separate the groups.

3.1.2. LDA and ANN

The LDA model used six parameters: mean RR, kurtosis, ΔRR, AF frequency, amplitude and difference in amplitude in first and last 30 s, and achieved a score of 19/20 correct classifications for groups N and T of the learning set. The same score was achieved by the ANN with three input parameters: AF frequency, amplitude and kurtosis.

3.2. Test set

Three algorithms: AF frequency, LDA and ANN were submitted as entries to the event 1 challenge and evaluated on the test set. Table 1 summarises the results for both the learning set and test set records.

Table 1. Learning and test set results for the challenge event 1 algorithms.

Score	AF frequency	LDA	ANN
Learning set	17/20	19/20	19/20
Test set	24/30	18/30	23/30

4. Discussion and conclusions

Of the parameters which we have assessed in this analysis, AF frequency appeared to be the most powerful in predicting the spontaneous termination of atrial fibrillation. It is known that drug treatment of atrial fibrillation leads to a reduction in fibrillation frequency prior to termination in patients with chronic atrial fibrillation. Our results suggest a similar mechanism may be responsible for termination in paroxysmal atrial fibrillation without drug intervention. The combined parameter analyses of LDA and ANN also featured AF frequency as a parameter. Difficulties in determining the AF frequency lie in removal of the ventricular components of the ECG. QRST subtraction is sufficient when there is little variability in the morphology of the QRST waves, but when QRST shape is variable large ventricular components remain in the residual signal and affect the frequency analysis as can be seen in record 3 of group N in figure 4.

We hypothesised that the slowing of atrial fibrillatory waveform would be accompanied by organisation of the ventricular rhythm. An apparent stabilisation of ventricular beat-to-beat interval was detected by ΔRR.

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