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Paroxysmal atrial fibrillation prediction method with shorter HRV sequences

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ABSTRACT

This paper proposes a method that predicts the onset of paroxysmal atrial fibrillation (PAF), using heart rate variability (HRV) segments that are shorter than those applied in existing methods, while maintaining good prediction accuracy. PAF is a common cardiac arrhythmia that increases the health risk of a patient, and the development of an accurate predictor of the onset of PAF is clinical important because it increases the possibility to stabilize (electrically) and prevent the onset of atrial arrhythmias with different pacing techniques. We investigate the effect of HRV features extracted from different lengths of HRV segments prior to PAF onset with the proposed PAF prediction method. The pre-processing stage of the predictor includes QRS detection, HRV quantification and ectopic beat correction. Time-domain, frequency-domain, non-linear and bispectrum features are then extracted from the quantified HRV. In the feature selection, the HRV feature set and classifier parameters are optimized simultaneously using an optimization procedure based on genetic algorithm (GA). Both full feature set and statistically significant feature subset are optimized by GA respectively. For the statistically significant feature subset, Mann–Whitney *U* test is used to filter non-statistical significance features that cannot pass the statistical test at 20% significant level. The final stage of our predictor is the classifier that is based on support vector machine (SVM). A 10-fold cross-validation is applied in performance evaluation, and the proposed method achieves 79.3% prediction accuracy using 15-minutes HRV segment. This accuracy is comparable to that achieved by existing methods that use 30-minutes HRV segments, most of which achieves accuracy of around 80%. More importantly, our method significantly outperforms those that applied segments shorter than 30 minutes.

1. Introduction

Atrial Fibrillation (AF) is the most common sustained cardiac arrhythmia that affects 1–2% of European population [1]. More than 6 million Europeans suffer from this arrhythmia and the number is expected to at least double within the next 50 years. Although occurrence of AF is not life-threatening arrhythmia, it increases overall risk of mortality, stroke, heart failure, hospitalization, and results in impaired cognitive function [2]. About 15% of strokes occur in people with AF. AF also causes symptoms such as palpitation, dizziness and generalized weakness that can decrease the quality of the patient's life. Atrial Fibrillation can be divided into paroxysmal atrial fibrillation (PAF), persistent atrial fibrillation and chronic atrial fibrillation. Occurrence of PAF lasts from several minutes to days but it is self-terminating. Persistent AF is similar to PAF but it cannot stop by itself without external treatment such as medication

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or electrical shock. Occurrence of chronic atrial fibrillation cannot return to normal heart beat even with treatment. The aim of therapy is to prevent stroke and regain normal rhythm [3]. Patients often start with PAF and then slowly evolve to chronic stage.

Therefore, the development of an accurate predictor of onset of PAF has become clinically more important today because it increases the possibility, with different pacing techniques, to stabilize (electrically) and prevent the onset of atrial arrhythmias [4]. This can lead to decrease in symptoms, and possibly a decrease in atrial remodeling that causes increased susceptibility to future episodes of PAF [5]. In addition, it may reduce the risk of strokes and thromboembolic events.

The main objective of this paper is to propose a PAF onset prediction method that reduces the time duration of the HRV signal required in feature extraction while maintaining good prediction accuracy level. It is a challenging task as demonstrated by previous works, in which relatively poor prediction accuracies were obtained when the signal lengths were reduced to less than 30 minutes. In this paper, the proposed method is investigated for different HRV signal lengths of 5, 10, 15, 20 and 30 minutes. 5 minutes is the recommended minimum HRV length by the task force of *European Heart Journal* [6]. Both full feature set and statistically significant feature set up to 20% are optimized by genetic algorithm (GA) respectively and related optimization results are analyzed.

2. Related work

There have been much research on method predicting the onset of PAF that are based on electrocardiogram (ECG) signal. These works can be classified into premature atrial complexes (PAC) detection [7–9] and heart rate variability (HRV) analysis [10–14]. Among the previous works based on PAC detection, Tran et al. [9] achieved highest prediction accuracy with 90%. They showed that PAF onset could be predicted by applying three criteria, namely the number of isolated PACs not followed by regular RR interval, runs of atrial bigeminy and trigeminy, and length of any short run of paroxysmal atrial tachycardia. Among the existing methods based on HRV analysis, Mohebbi and Ghassemian [11] achieved the highest accuracy with 94%, which outperformed all existing works on PAF onset prediction. They employed HRV features such as time domain feature, autoregressive features, sample entropy, poincare plot and bispectrum features. Unlike the method proposed by Tran et al. [9], the advantage of this method is that it does not need to specify that both records are from the same subject in order to predict the PAF onset.

Regardless of whether HRV analysis or PAC detection, almost all existing methods, which achieved acceptable prediction accuracies (of 80% and above), employed 30 minutes signal for feature extraction. Only a few previous works investigated shorter ECG or HRV signal for PAF onset prediction. However, the accuracies achieved were significantly lower than 80% [7,9–12,14]. For example, Yang and Yin [13] proposed a feature extraction algorithm called footprint analysis, in which features were extracted from 10 minutes of HRV signal. The achieved prediction accuracy was significant lower with 57%. Hickey and Heneghan [8] also evaluated their proposed method by using fast Fourier transform (FFT) to extract spectral features from shorter HRV signals. They achieved prediction accuracies of 68%, 70%, and 66% for 5, 10 and 30 minutes of HRV signal respectively.

Based on the review above, previous works show that HRV-based prediction methods of PAF onset require at least 30 minutes of HRV signal to achieve acceptable accuracy level. Several issues need to be considered here. Although 30-minute HRV segment is short as compared to 24 hours of HRV signal, it does not meet the recommended signal length for short term HRV analysis [6]. The suggested signal length for short term HRV analysis is 5 minutes. Furthermore, longer duration of input also introduces longer processing time in the feature extraction stage which may prove prohibitive in real-time application.

One of the main treatments for PAF patient is using an Implantable Defibrillator Device (ICD) to restore the normal rhythm [5]. A PAF onset predictor can enable ICD to anticipate the PAF onset possibly allowing it to be terminated early. In recent years, much research [15–17] have been performed to address the power consumption issue in ICD or similar devices that use HRV analysis for real time disease diagnosis. In the case of PAF onset prediction methods, the main concern is that long duration of signal and compute-intensive HRV analysis may burden the ICD battery life, and consequently shortening its operation time. Hence, more frequent surgery processes to replace the ICD battery are required, which can affect the health of the patient [15]. (Generally, the ICD device is expected to operate for more than 5 years after it is implanted in the human body). A final point in favor of a shorter HRV segment is that ICD needs to operate in real time so that it immediately restores sinus rhythm once the arrhythmia is detected. Long input signal can introduce larger timing lag between input and output of the prediction algorithm as compared to short term HRV analysis.

The layout of the paper is as follows. Section 3 presents the database and proposed method. Results and discussion are presented in Section 4. Finally, conclusion and future works are given in Section 5.

3. Proposed PAF onset prediction method

The block diagram in Fig. 1 shows the overview of the proposed prediction method. It comprises of the stages of pre-processing, HRV feature extraction, feature selection and support vector machine (SVM) based classification. Initially, electrocardiogram (ECG) signal is fed to the pre-processing stage. QRS complexes of the ECG signal are detected for HRV quantification. After that, ectopic beats in the quantified HRV are corrected and HRV sequences are resampled to 4 Hz. In HRV feature extraction stage, time-domain, frequency-domain, non-linear and bispectrum features are extracted from quantified HRV. Our HRV feature extractions are based on various algorithms that have been reviewed in Rajendra Acharya et al. [18]. In feature selection, Mann–Whitney *U* test is applied to find the HRV features that can pass the statistical test at 20% significance. Genetic algorithm (GA) is then used to select optimal feature subset from the full feature set and statistically significant feature re-