Automatic Detection of Conducted Premature Atrial Contractions to Predict Atrial Fibrillation in Patients after Cardiac Surgery

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Abstract

A method was developed to automatically detect conducted Premature Atrial Contractions (PACs) from the ECG signal. The method consisted of identifying the R waves of the ECG signal, determining the irregular beats that correspond to premature beats and dissociating atrial and ventricular premature beats. The method was developed using the ECG signals from Physionet and Cardio-Vascular Intensive Care Units (CVICUs) at the Cleveland Clinic. The developed method was applied on ECG signals collected from 24 post-cardiovascular surgery patients that developed AFIB. Out of the 24 patients, 21 patients had significant number of PACs before AFIB. Additionally, in these patients either a pattern of sustained cyclical PAC activity or bursts of intermittent PAC activity were observed.

1. Introduction

Atrial fibrillation (AFIB) is a common arrhythmia that is prevalent in post-cardiovascular surgery patients. It has been clinically observed [1] that approximately 25% of such patients develop AFIB mainly during post-operative days two and three. Though some of these patients may have previous history of AFIB, a significant fraction (47%) has new onset of AFIB post-operatively. These patients are at high risk for cerebrovascular accidents, hypertension, pulmonary edema, or the need for permanent post-surgery pacemaker. Additionally, post-surgical AFIB patients generally have longer hospital stay [2] and higher hospitalization costs. If AFIB can be predicted beforehand, prophylactic drug therapy can be applied to either prevent or minimize the risk of AFIB. Hence a reliable method to predict AFIB in post-surgical patients will dramatically improve patient care and surgical recovery.

Several studies that focused on developing methods to predict AFIB are described in the literature. Many of them [3-6] analyzed body-surface ECG to determine characteristics typical of AFIB patients. In the time domain, characteristics such as P wave shape [3] and RR interval variations [4] were studied to see if they showed variations before the commencement of AFIB. In the frequency domain, a similar focus has been placed on changes in characteristics such as isoelectric line and P wave frequency content [5]. Though some changes in the above-mentioned ECG characteristics were observed for patients with AFIB, they were either small or inconsistent to provide a reliable way to predict AFIB. Moreover, some of the characteristics such as P-wave shape and atrial late potentials are difficult to measure reliably in a clinical setting, especially by automatic real-time algorithms.

In addition to the above-mentioned ECG characteristics, clinical studies [1,6] have indicated the presence of PACs in AFIB patients, especially before the occurrence of AFIB. Though such qualitative indications are promising, it is still unclear if PACs can serve as reliable predictors of AFIB. Moreover, the relationship between PACs and post-cardiac surgery AFIB remains unexplored. It is also unclear if there exist specific patterns of occurrence of PACs before the onset of AFIB.

The overall goal of our research is to develop PAC based predictors of AFIB by analyzing the occurrences and patterns of PACs over a long duration. These predictors will be developed such that they can be clinically applied to monitor post-surgical patients who have undergone cardiac surgery. To achieve the above goal it is imperative that a method be developed to automatically detect and classify PACs in the ECG. This technique should function reliably and in real-time to be clinically applicable. The current paper describes the development and verification of such a technique. Using this technique it is demonstrated how ECG signals from Cardio-Vascular ICU (CVICU) patients can be analyzed to evaluate the occurrence of PACs before the onset of AFIB.

2. Methods

A Premature Atrial Contraction (PAC) is a stimulus from an ectopic atrial site that travels across the atria via atypical pathways. The PAC stimulus precedes the stimulus originating from the SA-node. A PAC that gets propagated through the AV node into the ventricular region thus triggering a ventricular contraction is called a conducted PAC. Non-conducted PACs do not get propagated to the ventricles mainly due to refractoriness of AV-node of Bundle of His. Compared to non-conducted PACs, conducted PACs are more easily and reliably identifiable on the ECG. For this reason, detection of conducted PACs will be the focus of the present study. In general, on the ECG, conducted PACs produce "normal" looking QRS complex that precedes the QRS complex initiated by the SA-node activity. This ECG feature is automatically detected by the proposed algorithm to identify conducted PACs.

2.1. ECG Data

ECG data from two sources were used. The first data source comprised of ECG signals from Physionet [7] that were originally made available for 2001 Computers in Cardiology Challenge. This was used as training data to establish an initial set of values for the various threshold parameters used in the algorithm. A second data set comprised of ECG signals collected from AFIB patients in Cardiovascular Intensive Care Units at the Cleveland Clinic Foundation. This data set was collected using a MARS station (GE Medical Systems, Milwaukee WI). The MARS station is an ECG acquisition and analysis system that collects ECG data from patient monitors. Part of the MARS data was used to refine the algorithm while the other part was used to explore patterns of PACs in AFIB patients. MARS data set had 4 channels ECG data with a maximum duration of 28 hours.

2.2. PAC detection algorithm

Detection of PACs was conducted in two steps. In the first step, the ECG was segmented into individual beats by detecting the R-waves. As the second step, conducted PACs were identified using the RR-interval information and the ECG data.

To detect the R-waves, the ECG signal was at first band-pass filtered (0.5-38Hz) to remove physiological and non-physiological noise. The sign of the R-wave was determined by noting the direction of maximum deflection. This was necessary because the R-wave deflection could be positive or negative depending on the selected ECG leads. The first derivative of the ECG was computed and the extreme points were identified using an adaptive amplitude threshold algorithm. Starting with the extreme points, a refined search was performed on the ECG to find the exact maximum or minimum that corresponded to the R-waves. To eliminate artifactual peaks that were wrongly identified as R-waves, a multi-channel comparison among the marked peaks on the two ECG channels was performed. Only those R-waves that were identified on both the channels were selected.

2.3. Detection of PACs

To detect PACs the R-wave annotation information generated in the previous step and the original ECG data were utilized. The various steps involved are outlined in Figure 1.

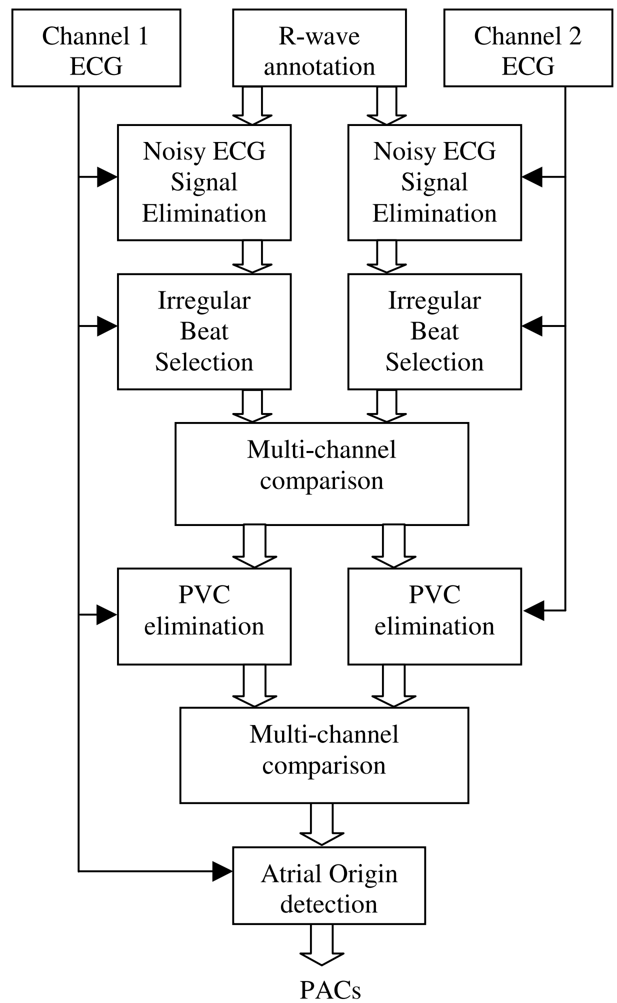


Figure 1. Flow diagram of conducted PAC detection algorithm.

As the first step, segments of ECG signals that have either excessive noise or missing information in one of the channels were eliminated along with any false R-waves that were detected in these segments.

In the Irregular Beat Selection module the R-wave annotation information was analyzed to detect irregular beats. Irregular beats were identified as the ones that did not fall within the range:

$$0.8RR_m \leq RR \leq 1.25RR_m \qquad (1)$$

where RR_m was the average of the RR-intervals defined by the last six normal cardiac cycles and RR was the interval between the R-wave of the questionable beat and the R-wave of the previous beat. As a conducted PAC initiates a QRS complex that precedes a normal one, QRS complexes corresponding to conducted PACs were selected as those that satisfy the relation:

$$RR < 0.8RR_m \qquad (2)$$

The results were compared between channels and only those irregular beats that occurred on both the channels were considered for further analysis. The detected irregular beats could either be of supra-ventricular or ventricular in origin. The irregular beats of ventricular origin such as those caused by Premature Ventricular Contractions (PVCs) were eliminated by a PVC detection module. This module utilized the fact that PVC generated QRS complexes are generally wider and of different amplitude than the normal QRS complexes or those triggered by PACs. Only those irregular beats that satisfied the following conditions (equations (3) and (4)) were considered having an atrial origin:

$$0.5QS_m < QS < 2QS_m \qquad (3)$$

$$0.66QR_m < QR < 1.33QR_m \qquad (4)$$

In equation (3), QS was the interval between Q-wave and S-wave of the premature beat and QS_m was the average width of normal adjacent beats. In equation (4), QR was the magnitude between the peaks of Q-wave and R-wave of the premature beat and QR_m was the average of the QR amplitude values of the last six normal cardiac beats. A multi-channel comparison was performed and if a premature beat was identified as PVC in one of the channels, it was eliminated from further analysis.

The last step, atrial origin detection, verified the existence of P waves before the irregular QRS complexes. The P wave was identified by squaring the first derivative of the ECG signal in a window of 100 ms before the QRS complex. A threshold was defined using the normal adjacent beats and if the amplitude of the squared signal was above the threshold, a P-wave was detected. Equation (5) describes the P-wave detection:

$$\max\left[\left(\frac{dP_k}{dt}\right)^2\right] \geq \frac{3}{8} * \left\{\max\left[\left(\frac{dP_{k-1}^{normal}}{dt}\right)^2\right] + \max\left[\left(\frac{dP_{k+1}^{normal}}{dt}\right)^2\right]\right\} \qquad (5)$$

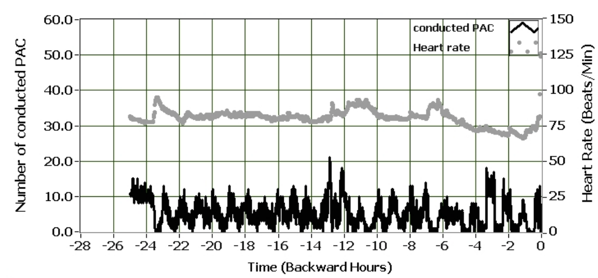
In equation (5), dP_k/dt was the first derivative of ECG before the QRS complex corresponding to the questionable PAC. dP_{k-1}^{normal}/dt and dP_{k+1}^{normal}/dt were the first derivatives of ECG before the QRS complexes of adjacent normal beats. In general, the P-wave has the largest amplitude on lead II of the ECG signal. Hence, the detection of P wave was made only on the lead II ECG signal.

3. Results

3.1. Algorithm verification

To verify the accuracy and specificity of the algorithm, eight 15-minute ECG segments were randomly selected from data collected by the MARS station. The selected data belonged to different AFIB patients and included PACs. However, the selected data was not part of the data set used for training the algorithm. Using a custom software package a cardiologist manually marked conducted PACs in the selected ECG signals. The PAC detection algorithm was applied to the same set of signals and the results were compared against those obtained by the cardiologist. The total number of PACs marked by the cardiologist was 828, while the algorithm marked 822. The accuracy of the algorithm was 88% while the specificity was 87%.

3.2. PAC patterns in AFIB patients



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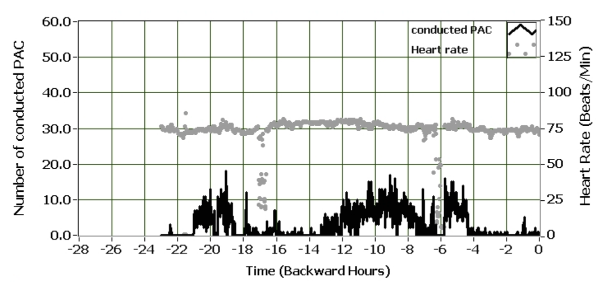

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Figure 2. Patterns of PAC activity before AFIB. The time "0" on the X-axis corresponds to the time when the patient had AFIB

The patterns of PAC occurrence in AFIB patients were determined by applying the developed algorithm on ECG data collected from AFIB patients. Specifically data was collected from post cardiovascular surgery patients from the time they were admitted in the ICU till they developed AFIB. Patients who were either paced or had chronic AFIB were not considered for analysis. ECG data was collected from a total of 24 patients and the total length of data ranged from 4 to 27 hours. The PAC detection algorithm was retrospectively applied to automatically mark the PACs. The PAC activity was computed as the number of PACs per minute.

Out of the 24 AFIB patients, 21 patients had significant PACs (>100) before AFIB. Additionally, when the PAC activity was charted over time, two types of patterns were revealed. In the first pattern, a constant, but cyclic PAC activity was observed (Figure 2a.). In the second pattern bursts of PAC activity interspaced by periods of relatively subdued or no PAC activity was observed (Figure 2b.).

4. Discussion and conclusions

Clinical indicators do suggest that episodes of AFIB during post cardiac surgery are probably initiated by triggers such as PACs in patients with susceptible underlying atrial substrate [1]. However, whether PACs or their patterns of occurrence can predict AFIB in post surgical patients remains unclear. In this paper we describe the development of a software algorithm that can automatically detect conducted PACs in ECG signals The developed algorithm can be applied in real-time on ECG data collected from post-surgical patients in an ICU environment. The algorithm was based on identifying ECG characteristics unique to PACs. The various parameters used in the algorithm were continuously updated to adapt to varying ECG shapes and characteristics that are commonly encountered in cardiac surgical patients.

The ability of the developed algorithm to explore whether PACs can predict AFIB is demonstrated by applying the algorithm on ECG data collected from 24 AFIB patients. When the PACs detected by the algorithm were analyzed it was revealed that significant number of PACs occurred in most patients before AFIB. Additionally, it was also revealed that the PAC activity generally occurred in two distinct patterns. In the first pattern, a sustained, but cyclical activity preceded AFIB while the second pattern showed bursts of PAC activity inter-spaced by either no or relatively quiet PAC activity. But, it remains to be seen whether such patterns exist in a larger patient population. Additionally, it is also remains to be explored whether such patterns are unique to AFIB patients. However, this preliminary study indicates that PACs and their patterns of occurrence could act as predictors of AFIB in post-cardiac surgery patients.

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