

An Automated Algorithm for the Detection of Atrial Fibrillation in the Presence of Paced Rhythms

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Abstract

Approximately 5% of diagnostic ECGs acquired in the hospital setting are from patients with pacemakers. A significant percentage of these patients are in atrial fibrillation or flutter (AF), and have increased risk of stroke. Many automated diagnostic algorithms abort analysis when paced rhythms are identified. The Philips DXL algorithm can detect AF in the presence of paced rhythms and provides interpretations for both rhythms.

The algorithm uses QRST subtraction with frequency domain analysis of the residual. A decision tree classifier uses features from the power spectrum, as well as irregularity of non-paced beats.

On a training database of 355 paced ECGs with 265 in AF, the algorithm had AF detection sensitivity of 76%, PPV of 82%, and specificity of 73%. On a testing set of 1,057 paced ECGs with 194 AF cases, the algorithm had sensitivity of 71%, PPV of 83%, and specificity of 97%.

Automated detection of AF in the presence of pacing is a clinically valuable tool to assist cardiologists in ECG diagnosis, and can be done with relatively high accuracy.

1. Introduction

Approximately five percent of 12-lead resting ECGs acquired in hospitals are from patients with pacemakers. A significant percentage of these patients are in atrial fibrillation or flutter (AF) [1-3]. Many automated 12-lead ECG diagnostic algorithms abort analysis when paced rhythms are identified, and thus do not attempt to detect AF, and physician overreading commonly misses it [2-3]. However, identification of AF is key to patient management and anticoagulation therapy to prevent thromboembolic events such as cerebrovascular accident (CVA) [3-5]. Most pacemaker recipients are elderly and have a high prevalence of AF. Missing a diagnosis of AF by the cardiograph and therefore by the cardiologist in the admission ECG could potentially cause further complications to the patients. This issue becomes more important in the presence of intermittent pacing when there may be only a few paced beats and obvious AF that

is ignored by the diagnostic cardiograph algorithm. On the other hand, in the presence of continuous pacing, detection of AF can often be difficult, as there may only be subtle clues due to the interference in the waveform from pacing artifact and to the presence of regular ventricular rhythm due to fixed-rate pacing (Figure 1). Normally, R-R variation is the main feature used for AF detection, but in the presence of pacing, atrial signal characteristics must be analyzed. The Philips DXL automated diagnostic ECG algorithm contains a special design for detection of AF in the presence of paced rhythms.

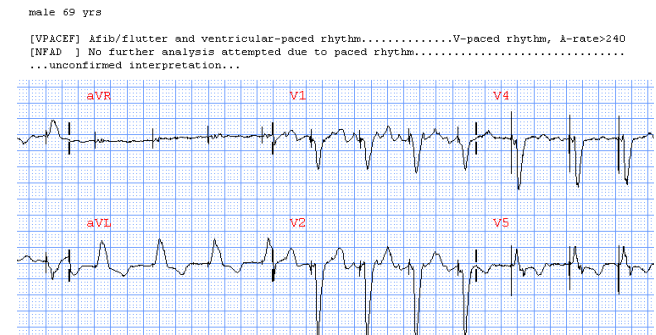


Figure 1. A cropped 12-lead ECG report shows that detection of AF in the presence of continuous ventricular pacing is difficult both for clinicians and automated algorithms since R-R variation is absent. Digital extraction of the atrial signal is necessary.

2. Methods

The algorithm is designed to detect paced rhythm and atrial fibrillation independently. The algorithm then combines the output from AF and paced rhythm detection and generates appropriate rhythm interpretation.

2.1. Paced rhythm classification

Pacemaker pulses are detected on each lead of acquired ECG using a software algorithm [6]. Detection of narrow, low-energy bipolar pulse can be accurately

performed on 500 sample-per-second, 150 Hz. low-pass filtered waveform because the energy of the pacemaker pulse is captured by the high-frequency sigma-delta A/D converters used in the Philips cardiographs. A multi-lead resolver determines the global cross-lead set of pulses, and these are associated with each detected beat if they fall within certain time-regions. Each beat is classified as intrinsic: normal or ectopic; or paced: atrial, ventricular, or dual chamber.

Paced rhythm is determined by examining the sequence of beat classifications. The algorithm distinguishes continuously paced “rhythms” where all beats are paced from intermittent paced “complexes” present if there are also non-paced beats. Atrial-sensed ventricular-paced, atrial, ventricular, and dual paced complexes and rhythms are classified, and dual pacing with intermittent inhibition is noted if dual chamber pacing is detected but not all beats are dual paced.

2.2. Atrial fibrillation detection

Atrial fibrillation is detected by the DXL algorithm in the same general way for paced and non-paced rhythm, but additional rules are used for the paced rhythm case. Classification of atrial fibrillation and atrial flutter is accomplished with a linear discriminator using RR interval features and characteristics of the atrial signal. Using a common method, the atrial signal is estimated by subtracting the average QRST complex from the signal leaving the residual as the atrial signal [7]. Pacer spikes are removed before coherent beat averaging and QRST subtraction.

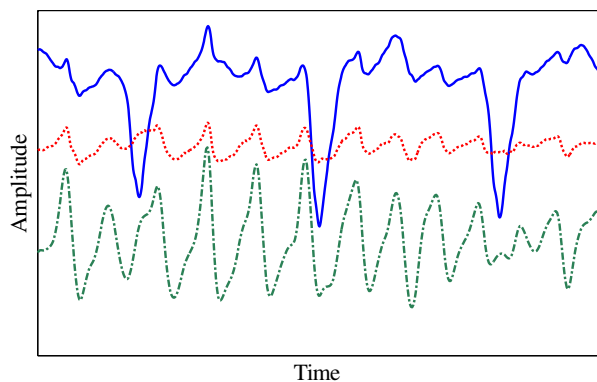


Figure 2. A short segment of lead V1 of a paced ECG is shown (top) along with the residual of QRST subtraction (atrial residuum) (middle) and the band-pass filtered version of the atrial signal (bottom). Note that the pacer spikes have been removed to prevent corruption of the atrial signal processing.

Figure 2 shows waveforms to illustrate the QRST subtraction and the resulting atrial signal. QRST complexes of the same shape are averaged together coherently from QRS onset through the end of the T-wave. Subtraction of the QRST complex from the waveform is performed with first difference signals so that after integration (reversing the first difference operation) there are no amplitude discontinuities due to differences in baseline at each beat. For beats with a different shape from the average, the beat is zeroed. Since atrial fibrillation (AF) and atrial flutter have atrial rates between 200bpm and 800bpm, the atrial signal can be bandpass filtered for noise reduction and downsampling.

Variation in the RR interval is often the main ECG feature used for atrial fibrillation detection [8]. In the case of paced rhythms however, RR interval variation can no longer be the main feature for detection. For classification of coarse atrial fibrillation and atrial flutter, the power spectrum and autocorrelation of the atrial signal provide good discrimination [9,10]. The median frequency provides the atrial rate. The median frequency is calculated from the power spectrum where half the power lies above the frequency and half the power is contained below the frequency. In our case, a Welch periodogram with a Kaiser window is used to calculate the power spectrum for each ECG lead used in the atrial signal analysis (Figure 3). The autocorrelation function (ACF) is the inverse FFT of the power spectral density (PSD) (Figure 4). Features are calculated for each lead used in the atrial signal analysis, leads I, II, III, V1 and V2. Global values are used in the linear discriminator. Global values are taken from the best lead where the best lead for ACF parameters is the lead with the highest 1st and 2nd peaks in the ACF. For the PSD, the best lead is the lead with the highest peak PSD at any one frequency.

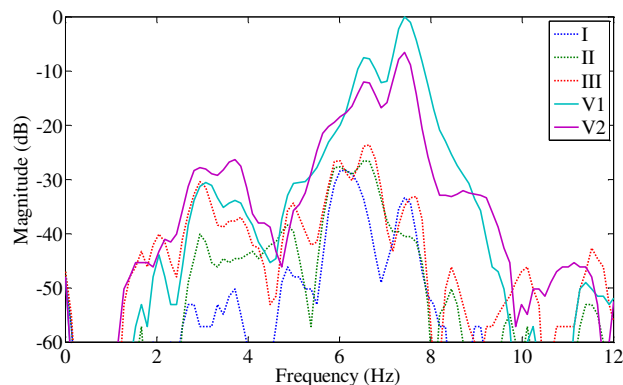


Figure 3. For the example paced ECG, the power spectrum is shown for the filtered QRST residual of all leads used in the AFIB/AFLT analysis. The signal power is greatest in leads V1 and V2 and the main frequency is near 8Hz.

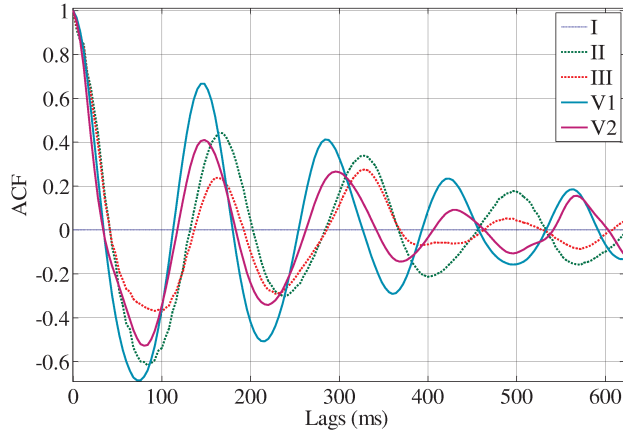


Figure 4. The normalized autocorrelation for each lead was derived from the PSD in Fig 3. The main frequency of approximately 8Hz corresponds to the cycle length of just over 125ms.

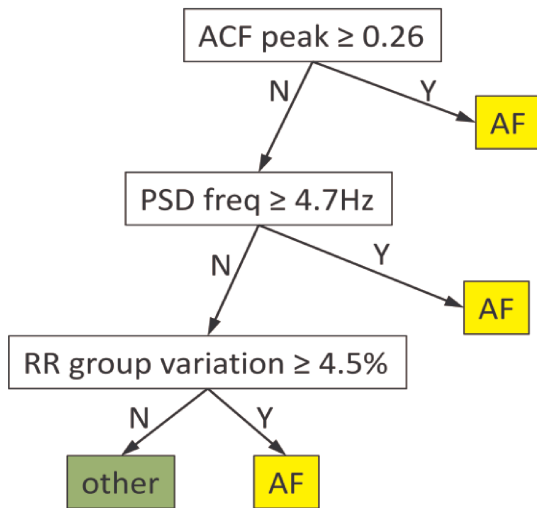


Figure 5. The decision tree used to discriminate atrial fibrillation and atrial flutter from other rhythms or noise uses the three variables (1) ACF peak: height of the first normalized autocorrelation peak, (2) PSD freq: frequency of the main peak in the power spectrum and (3) RR group variation: the RR interval standard deviation divided by the mean RR interval for the largest grouping of RR intervals.

In addition to the common algorithm for AF and atrial flutter, paced rhythm processing uses an additional set of rules based on a decision tree as shown in Figure 5 above. The decision tree was trained using the training set and then pruned to result in a simple set of rules based on three ECG features. One rule not shown but common to all is the requirement for the observed atrial rate to be higher than 200bpm. The signal processing to derive the ACF peak and PSD frequency is clearly shown in the progression from Fig. 2, Fig. 3 and Fig. 4. The RR group

variation needs more detailed explanation. For arrhythmia analysis, beats are grouped by RR interval for two reasons, to exclude ectopic beats and to analyze the RR interval variation for non-ectopic beats. RR intervals are grouped by sorting the RR intervals and then splitting into groups when neighbouring RR intervals increase by more than 10% of the median RR interval. RR group variation (standard deviation divided by mean) is used to estimate the normalized RR variation in non-ectopic beats.

2.3. Database

Characteristics of the database used for pacemaker pulse detection and paced rhythm classification have previously been published with performance results of the paced algorithm [6]. Based on high performance in identification of paced rhythms (sensitivity 97.2%, specificity 99.9%), the algorithm was used to identify paced ECG cases for testing.

For the detection of atrial fibrillation in the presence of paced rhythms, an algorithm training database was developed containing 355 pacemaker ECG records with 265 (75%) presenting with atrial fibrillation.

A testing database was selected from an initial set of 42,817 sequential ECGs from the emergency department of a teaching hospital. All ECGs classified to have any ventricular pacing (continuous, intermittent, or dual) by the automated paced rhythm algorithm were used to create the testing subset of 1,057 ECGs. In this paced subset, 194 cases (18%) were identified by two expert readers to contain AF.

Table 1. Database used in training and testing of AF detection in the presence of paced rhythms.

	TRAINING	TESTING
Paced	355	1,057
AF	265 (75%)	194 (18%)

3. Results

The performance results are listed in Table 2. On the test and training database the algorithm had similar sensitivity and positive-predictive value, but the specificity was significantly different which is not unexpected because the proportion of AF in the two data sets is quite different. The algorithm's performance in detection sensitivity compares well with reported clinician overreading detection rates [2-3], while still providing a good positive-predictive value.

Table 2. Performance results of the AF algorithm in the presence of paced rhythms.

	TRAINING	TESTING
Sensitivity	76%	71%
PPV	82%	83%
Specificity	73%	97%

4. Discussion

The reference used for comparison was expert overreading of the ECG records. No gold standard was available such as patient clinical history of atrial fibrillation, or change or suspension of electronic pacing to help with the reference annotation. For this reason, the overreaders were dependent on the characteristics of the atrial signal just as the computer algorithm was dependent. Coarse atrial fibrillation and atrial flutter can be recognized by the large amplitude repetitive atrial signal, but fine atrial fibrillation can only be robustly detected with the help of RR interval variation characteristic of atrial fibrillation. Therefore, fine atrial fibrillation could only be recognized for the subset of ECGs with a minority of paced beats which retained the characteristic random RR interval variation.

From the test results, the nature of the difference in test and training data set is apparent. The training set was a selected set while the test set was unselected except for paced rhythm. The training set had a higher percentage of paced cases, 75%, compared to 18% found in the test set. Patel et.al. found that the rates of AF detection by 12-lead ECG overreading were 20% and 44% in continuous versus intermittently paced ECGs with known AF status [3]. Carlsson et.al. measured AF incidence of 140 of 326 patients (43%) with dual chamber pacemakers, but temporary pacemaker reprogramming was necessary in 86% to determine AF status [5]. McLellan et.al. found an even higher incidence of AF at 71% and a sensitivity for detecting AF through 12-lead ECG alone was 70% [2]. These findings make it probable that AF cases were unrecognized in our test set, but also underscores the difficulty in detecting AF in all cases by ECG alone. On the other hand, the majority of cases of atrial fibrillation can be detected by ECG.

The automated algorithm has good performance compared to human overreaders. Sensitivity of AF detection in paced rhythm is lower than for non-paced rhythm, but we accept the lower sensitivity as a trade-off for high specificity.

5. Conclusion

Paced rhythm obscures detection of AF due to regulated ventricular rhythm. Detection of AF in the presence of paced rhythm is clinically important, especially for CVA prevention. Automated detection of AF in the absence of ventricular rhythm irregularity is possible with this advanced signal processing design. The DXL algorithm is capable detecting AF in the presence of paced rhythm with a relatively high degree of accuracy whether the rhythm is continuously or intermittently paced, and provides appropriate interpretation of AF with interpretation statements specifying ventricular/dual paced rhythm or complexes. Having this capability in the ECG interpretation is beneficial to clinical decision support for cardiologists in patient care.

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