

Sequential Analysis for Automatic Detection of Atrial Fibrillation and Flutter

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Abstract

A method for automatic detection of atrial flutter and fibrillation by sequential analysis of the atrial activity in a single ECG lead is developed. A previous method for automatic detection of atrial flutter/fibrillation was based on the assessment of atrial activity in TP segments. This approach is used in the present work, connected with 'P wave absence' and 'ventricular arrhythmia detection', forming a combined algorithm with three consecutive logic steps.

The proposed method has been applied on 329 records from a diagnosed atrial flutter-fibrillation database. An improvement of the total accuracy = 98.8% and Sensitivity= 95.7% was achieved mostly due to the reduction of false negative errors. The sequential analysis correctly detects 'fine' fibrillation where atrial activity is barely visible, and the effect of electromyogram noise was reduced.

1. Introduction

Atrial flutter (AFL) and atrial fibrillation (AFI) are due to inhomogeneity of repolarisation, inciting the formation of macroreentrant (for AFL) and microreentrant (for AFI) circuits in small areas of the atria [1]. AFL is relatively uncommon in adults. Its occurrence is about one-twentieth of that of AFI.

AFL in the electrocardiogram (ECG) is represented by waves of 'sawtooth'-like pattern and of relatively uniform shape, with rates between 200 and 350 min⁻¹. AFI waves are usually small and irregular in shape and duration, of rates about 400 to 600 min⁻¹. According to Wagner [1] atrial rate between 350 and 400 is sometime associated with mixed flutter/fibrillation - when atrial waves have some characteristics of both types at given time interval, or there are alternations between the two.

AFL produces a ventricular rhythm that varies from precisely regular at constant atrial/ventricular ratio of 1:1, 2:1, 4:1 (and rarely 3:1), to regularly irregular - for example 6:2 (triggered 4:1 and 2:1) and irregularly

irregular - with variable ratio. AFI always produces irregularly irregular ventricular rhythm [1].

The presence of abnormal atrial waves is reproduced in all ECG recordings, but it is masked by high amplitude QRS and T waves and is relatively well observable only in T-Q segments, predominantly in V1, and sometimes in the peripheral leads.

The amplitudes of AFI vary from 'coarse' prominent waves clearly visible in many leads to 'fine' - where the waves are slightly or not visible at all.

The extremely low or virtually zero amplitude waves makes the atrial abnormalities detection very difficult. It is practically easier to discriminate between AFL and AFI by waveform analyses in the TQ segment [2, 3] or by Fourier transformation [4], than to detect them. Christov et al. [5] report a sensitivity of only 76.1%, due to the false negative errors, all in cases of 'fine' AFL and AFI.

The electromyogram noise, which may accompany the ECG, although suppressed to some degree by filtering, leads to false positive detection by the wave rectification method [5].

This study proposes an algorithm for the automatic detection of atrial flutter and fibrillation by sequential analysis of atrial activity in a single ECG lead. Separate detection of those two types of arrhythmia is not performed.

2. Material and methods

The proposed method of automatic detection of AFL and AFI is based on the combined analysis of "P wave absence", "ventricular arrhythmia test", and "intensive atrial activity" in the TP segment, with the processing of a single ECG lead.

2.1. Atrial activity index

The proposed method is based on atrial flutter/fibrillation (AFF) parameter measurement in different segments of the RR interval. This index used as AFL/AFI identification is a quantitative representation of

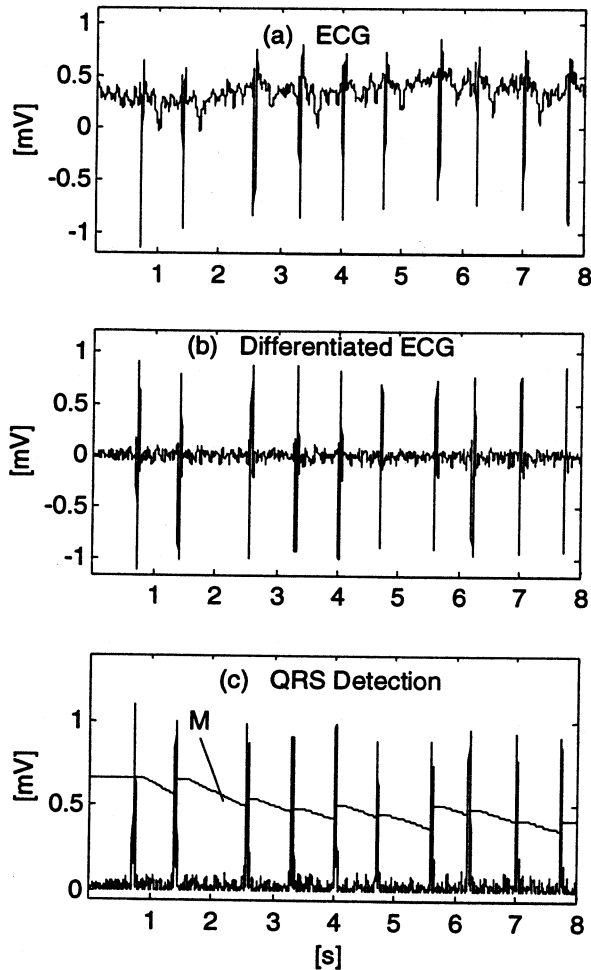


Figure 1. (a) ECG; (b) Differentiated ECG; (c) QRS detection by comparing a varying threshold value M to the absolute value of the differentiated ECG.

the residual atrial activity. The procedure defined in [5], includes the following steps:

- differentiation
- QRS detection and waves identification
- Interval subtraction
- Filtering
- Wave rectification and AFF parameter estimation

For example the AFF in the $T_{\text{offset}} - P_{\text{onset}}$ segments of the ECG and labeled as AFF_{TP} is characterized by the following steps:

- Differentiation of the ECG signal (Fig. 1b);
- QRS detection in the differentiated ECG (Fig. 1c);
- T_{offset} and P_{onset} detection;
- P-QRS-T interval subtraction from the differentiated ECG (Fig. 2a);
- Approximation filtering (Fig. 2b);

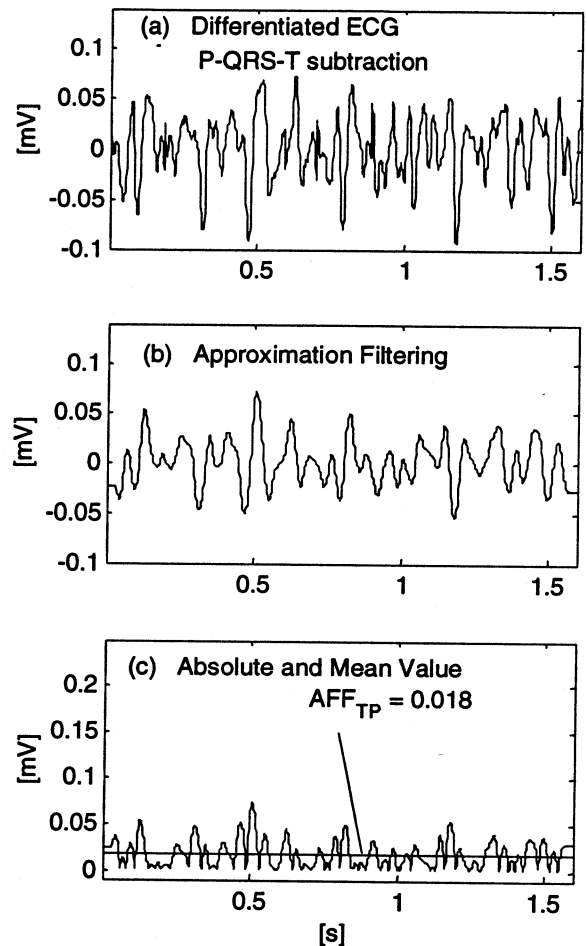


Figure 2. (a) Differentiated ECG after PQRST subtraction; (b) Approximation filtering; (c) Absolute values. The atrial flutter-fibrillation parameter (AFF) is calculated as a mean value in the interval.

- Measurement of the absolute mean value of the differentiated and filtered signal in the $T_{\text{offset}} - P_{\text{onset}}$ segments (Fig. 2c).

This index has been computed in all the 12 standard leads, showing higher accuracy in V1 lead [5]. Therefore the proposed algorithm was applied to a single lead: V1.

2.2. Automatic detection of AFL/AFL

The flowchart of the automatic detection of AFL/AFL algorithm is shown in Fig. 1. It is possible to characterize 3 main blocks:

- P wave test
- Arrhythmia test
- Atrial activity test

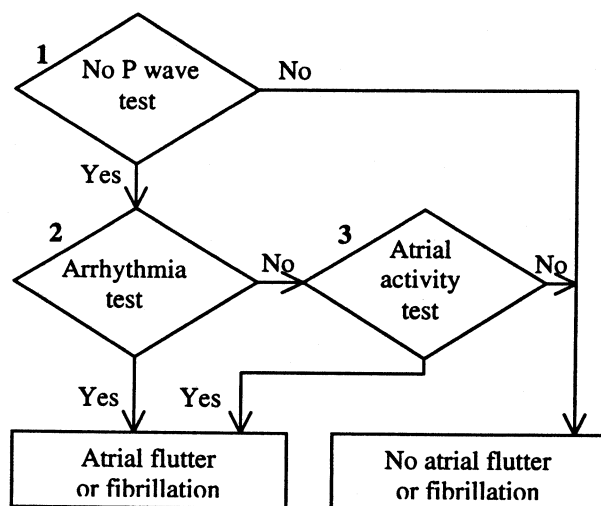


Figure 3. Flowchart of atrial flutter/fibrillation detection algorithm.

2.2.1. P wave test

The normal P waves in patients with atrial flutter or fibrillation are replaced by either flutter or fibrillation waves. It is not possible to decide that there is a 'P wave absence' only by the atrial activity in the P time-interval range.

The lack P wave is measured by the ratio AFF_{PQ}/AFF_{TP} , where AFF_{PQ} is the quantitative atrial activity index in the $P_{onset} - QRS_{onset}$ interval, and AFF_{TP} the atrial activity index in the TP interval. The condition of AFF_{PQ} twice the value of AFF_{TP} is considered as a threshold value for the P wave test.

For the example of Fig. 2 and Fig. 3, $AFF_{TP}=0.018$, $AFF_{PQ}=0.024$, and the ratio is equal to 1.33, with a positive outcome of the P wave test.

2.2.2. Arrhythmia test

The arrhythmia test is based on the check of RR intervals constancy. The QRS detection is based on the absolute value $abs(D)$ of the differentiated ECG signal (Fig. 1c), with an algorithm proposed by Dotsinsky [6]. The QRS fiducial point occurs at the first steep slope, and the subsequent measurement of RR intervals with this technique allows a high accuracy compared with other fiducial points of the QRS [7]. In the arrhythmia test, a check on the presence of constant RR intervals is performed, allowing a maximum deviation of 10% with respect to the mean value of RR in the previous 8 seconds. The presence of a jitter error in the fiducial point

connected to the RR interval variation is not critical for the purposes of the considered block.

2.2.3. Atrial activity test

The atrial activity test (block 3 of fig. 3) is performed in case of "P wave absence" and "no arrhythmia" obtained. The main purpose of this test is to detect regular flutter (flutter waves wrongly detected as P waves) at constant atrial/ventricular ratio (no arrhythmia). It consists in the quantitative measure of the residual atrial activity in the TP interval (AFF_{TP}). A relative threshold value for the AFL/AFI detection has been considered.

2.3. Experimental data

A set of 329 records from an ECG signal database was used for testing the proposed algorithm. The records were collected during routine ECG recordings in the Dept. of Cardiology, Sofia Medical Faculty Hospital. More than 80% of the patients had abnormal electrocardiograms. The database contains 8-channel records, of 2 peripheral and 6 precordial leads, taken with respect to the left leg electrode [8]. The sampling rate is 400 Hz, with a resolution $4.88 \mu V/bit$ and 8 seconds of recording length.

The database was annotated by a group of cardiologists. Atrial fibrillation was indicated in 87 patients, atrial flutter in 4 and mixed atrial flutter/fibrillation in 1 record.

The peak to peak QRS value was measured and the signal amplitude was normalized to 2 mV p-p. Thus the amplitude differences of AFI and AFL waves due to different patients anatomy, heart position, thorax shape, etc. were partly compensated. The best normalization factor would be the P wave amplitude, but as there is no normal P wave in cases of AFI and AFL, we chose the QRS peak-to-peak amplitude.

The atrial activity indices were evaluated as a percentage of the normalized QRS amplitude, and for example the threshold value of AFF_{TP} in the atrial activity test was set to 0.60%.

3. Results and discussion

The application of the proposed algorithm to the considered ECG records produced the following validation indices:

Total accuracy =	98.8%	(91.8%)
Sensitivity =	95.7%	(76.1%)
Specificity =	98.3%	(97.9%)

where the corresponding results obtained with the simple algorithm based on the AFF_{TP} index [5] are shown in brackets.

Several ECG recordings are shown in Fig. 4 with the corresponding logical decision paths (block-diagram of Fig.3).

It was mentioned in the introduction that AFI always produces irregularly irregular ventricular rhythm. The results show that patients with AFI (irrespective of wave amplitude – ‘coarse, medium or fine’) can be identified logically only by the lack of P wave in cases of arrhythmia (Fig.1).

The present method allowed a reduction of the false negative errors (from 22 to 5) compared to a simple algorithm based on the AFF_{TP} index [5]. An example of ‘fine’ fibrillation is shown in Fig 4 (5th ECG), where practically no atrial activity is visible.

The lack of P wave and arrhythmia logic detection is valid also for patients having AFL with ‘regularly irregular’ ventricular rhythm, for example 6:2 (triggered 4:1 and 2:1) and irregularly irregular – with variable ratio.

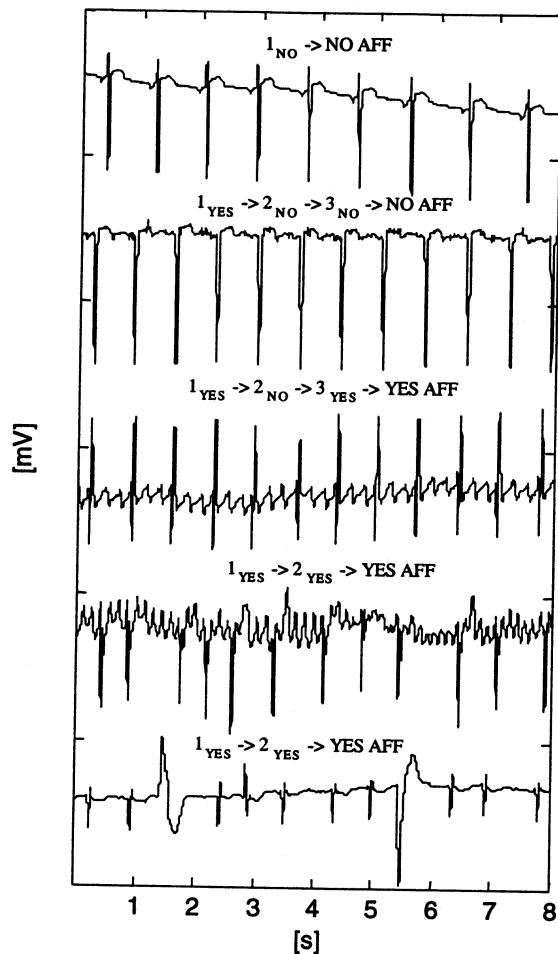


Figure 4. Five ECG recordings and their respective detection logical decision paths.

A logic test for atrial activity in the TP segment (Fig.1) is performed in cases of regular flutter at constant atrial/ventricular ratio of 1:1, 2:1, 4:1. This test allowed the record in Fig 4 (3rd trace) without arrhythmia, but with atrial flutter 4:1, to be properly classified as AFF.

The effect of electromyographic noise leading to positive errors was reduced, due to the ‘Lack of P wave’ test. The ratio AFF_{PQ}/AFF_{TP} is relatively insensitive to noise, as its amplitudes in AFF_{PQ} and AFF_{TP} are similar.

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