Automatic Detection of Atrial Fibrillation and Flutter Using the Differentiated ECG Signal

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Abstract

Atrial electrical activity during erratic heart rhythms, such as atrial fibrillation (AF) and flutter (AFL), are difficult to characterize quantitatively. In this work we investigated quantitative differences in ECG signals with AF and AFL. In each RR interval we analysed a set of windows to determine the characteristic waves of the AF and AFL (F waves). The method uses the differentiated and low-pass filtered ECG signal for the detection of F wave boundaries. The method has been applied to ECG records of the MIT-BIH database with a wide range of AF and AFL morphologies. The best statistical significance to separate AF from AFL has been obtained when analysing the variation coefficient of the F wave duration (VCFD): AF 0.368 ± 0.071, *AFL* 0.204 ± 0.068, $p < 0.001$. *When defining an ECG record as AF, if VCFD* > 0.255, *the clinical performance of VCFD for detection of AF presents a sensitivity of 90%.*

1. Introduction

To measure atrial electrical activity without invasive atrial recording electrodes, one must rely on electrocardiographic patterns of fibrillation/flutter wave (F wave) appearence which are both crude and subjective. Previously, F wave amplitude has been used in an attempt to quantify "coarseness" or "fineness" of AF [1,2]. Unfortunately, these semi-quantitative approaches have produced conflicting results [3], perhaps because atrial regularity is not necessarily accounted for simple measures of amplitude, or because the performance of algorithms for automated measurement of F waves degrades in the presence of noise [4].

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In this paper we present a method to estimate the onset and end of F waves. This method is based on a previously related procedure to estimate the P, QRS and T wave boundaries [5]. It makes use of the differentiated ECG signal and information about wave shape. The differentiation process avoids problems with baseline drift given that low frequencies are then attenuated. With the information about F wave presence, the system analyses the regularity of wave patterns to characterize AF and AFL. The method has been applied to ECG records of the MIT-BIH database [6] that exhibit a wide range of AF and AFL morphologies.

2. Methods

The procedure to characterize atrial fibrillation and flutter is composed of several steps: preprocessing, QRS detection, waves location, waves onset and end determination, and waves analysis.

2.1. Preprocessing

The first step consists of a filtering process for noise reduction and a nonlinear transformation to improve QRS detection [7]. Once the bandpass filtered signal (ECGPB) is reached, a low-pass differentiator is applied to get the information about changes in the signal slope. This differentiated signal is called ECGDER.

2.2. QRS detection

The QRS detector used in this work is an adaptation of that described in [7], using the signal slope in the decision rule. It includes a QRS selection in order to reject noisy beats.

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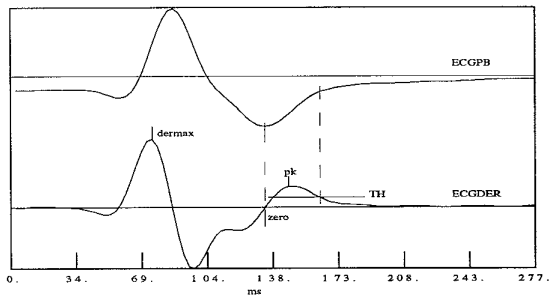

Figure 1. *Determination of the end of a wave by the threshold method.*

2.3. Waves location

The waves related with atrial electrical activity have lower frequency components than the QRS complex. Then, we again apply a low-pass filter to ECGDER to remove remaining noise. In each RR interval of this filtered signal we define a set of windows. The first one is defined just preceding the next QRS complex. In this window we search for the maximum and minimum value. If these values are bigger than a percentage of the maximum slope value of the QRS complex we consider the presence of a wave. The wave peak is assumed to occur at the zero-crossing between the maximum and minimum values in the window. The next window is defined preceding the onset of the previous detected wave and the same procedure is applied.

2.4. Wave onset and end determination.

Once we have the wave locations (zero-crossing point *(zero)* in the differentiated signal ECGDER), we proceed to determine the onset and end of each wave. The method used was presented in [5].

Figure 1 shows the procedure to determine the end point of a wave. From the *zero* point we search for adjacent peak *(pk)* on the right. This point is the point of maximum slope in the wave. A threshold is defined using the value of ECGDER at time instant *(pk)*, and we determine the end of the wave as the forward threshold crossing point from *(pk)* in the ECGDER signal. An equivalent procedure is applied to detect the wave onset.

After the onsets and ends of the waves have been detected, we search for the maximum and minimum value in the ECG (original signal) for each wave. If the difference between these values is higher than a threshold, we consider that the F wave is present.

2.5. Waves analysis.

The previously described steps have been applied to ECG records with a duration of 2 seconds. The presence or absence of waves defines if the baseline is pathological or normal. The amplitudes and durations of the F waves determines the shape of the baseline. The variability of the amplitudes and durations of the waves determine if the baseline undulation is regular, resembling a sawtooth edge (atrial flutter), or irregular (atrial fibrillation).

The diagnosis of the AF or AFL depends of the regularity of baseline undulations [8]. Thus, in each segment of 2 seconds we have calculated the following parameters: mean value (μ_a), standard deviation (σ_a) and variation coefficient (σ_a/μ_a) of the F wave amplitudes, and also mean value (μ_d), standard deviation (σ_d) and variation coefficient (σ_d/μ_d) of the F wave durations.

3. Results

In this study we have analysed 20 segments of AF and 20 segments of AFL from the MIT-BIH database [6]. The ECG lead configuration considered is: the upper channel (channel 0) is a modified limb lead *II* (MLII), and the lower channel (channel 1) is usually a modified lead V_1 (occasionally V_2 or V_5). Figures 2 and 3 show ECG records that present atrial fibrillation (record 201_2:05 and record 202_19:10). The dotted lines denote the identified F wave boundaries in each one of the channels. Figures 4 and 5 show ECG records that present atrial flutter (record 202_25:34 and record 202_25:41). Our analysis has been applied to the channel 1 because in this channel the F waves appear in a clearly way.

Table 1 shows the results of the statistical analysis when comparing the mean F wave duration (μ_d), and the variation coefficient (σ_d/μ_d), of the 2 seconds ECG records from patients with AF and AFL. The variation coefficient of the F wave duration (VCFD) presents a higher statistical significance than the mean F wave duration (MFD). Table 2 shows the results of the

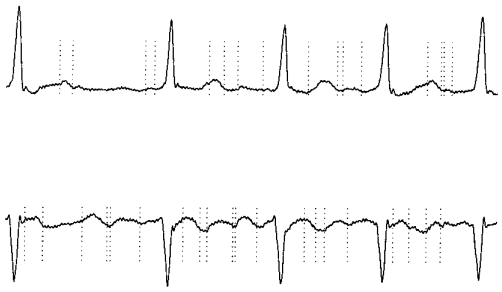

Figure 2. *Record 201_2:05, channel 0 (MLII) and channel 1 (V_1), MIT-BIH. Annotated Atrial Fibrillation.*

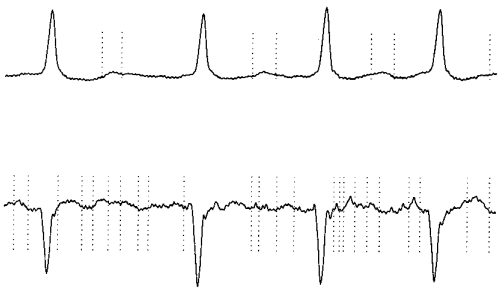

Figure 3. *Record 202_19:10, channel 0 (MLII) and channel 1 (V_1), MIT-BIH. Annotated Atrial Fibrillation.*

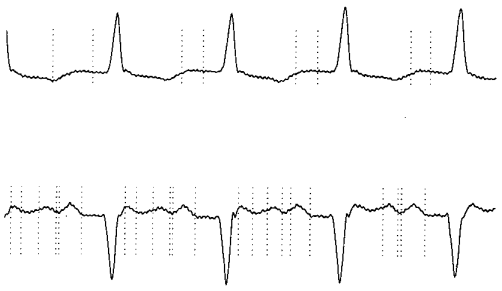

Figure 4. *Record 202_25:34, channel 0 (MLII) and channel 1 (V_1), MIT-BIH. Annotated Atrial Flutter.*

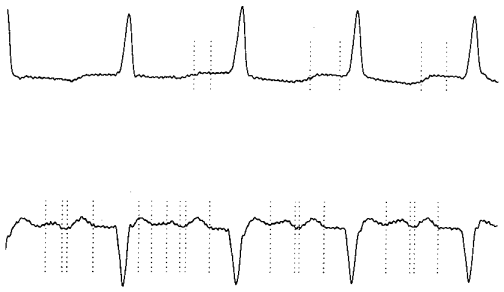

Figure 5. *Record 202_25:41, channel 0 (MLII) and channel 1 (V_1), MIT-BIH. Annotated Atrial Flutter.*

		μ_d (ms)	σ_d/μ_d
Group	*n*	$\overline{\mu_d} \pm SD$ (ms)	$\overline{\sigma_d/\mu_d} \pm SD$
AF	20	95.99 ± 16.37	0.368 ± 0.071
AFL	20	84.36 ± 10.76	0.204 ± 0.068
p		< 0.005	< 0.001

Table 1: *Average values and standard deviation of the mean (μ_d) and the variation coefficient (σ_d/μ_d) of the F wave durations, in ECG records of AF and AFL.*

statistical analysis when comparing the mean F wave amplitude (μ_a) and the variation coefficient (σ_a/μ_a) of the 2 seconds ECG records. In this case the variation coefficient of the F wave amplitude (VCFA) also presents the best results, but not so good as the results obtained with the VCFD.
When defining an ECG record as AF if $VCFD > 0.255$, and AFL if $VCFD \leq 0.255$, the clinical performance of VCFD for detection of atrial fibrillation presents a sensitivity of 90%, and also a sensitivity of 90% for detection of atrial flutter.

4. Conclusions

The information about the waves shape is very useful for ECG classification and cardiac diagnosis. We have developed a non-invasive technique to quantitatively characterize the differences between atrial fibrillation and flutter.

Group	n	μ_a (mV) $\overline{\mu_a} \pm SD$ (mV)	σ_a/μ_a $\overline{\sigma_a/\mu_a} \pm SD$
AF	20	0.240 ± 0.150	0.533 ± 0.274
AFL	20	0.165 ± 0.047	0.344 ± 0.098
p		< 0.025	< 0.005

Table 2: *Average values and standard deviation of the mean (μ_a) and the variation coefficient (σ_a/μ_a) of the F wave amplitudes in ECG records of AF and AFL.*

This method quantifies the notion that AFL signals present a regular baseline undulation. The technique has been applied to 20 segments of 2 seconds presenting AF, and 20 segments of 2 seconds with AFL. The variation coefficient of the F wave duration (σ_d/μ_d) has allowed to separate AF from AFL with a statistical significance of $p < 0.001$.
Prospective studies are required to determine if objective analysis of F wave characteristics may prove helpful in predicting responses to therapeutic interventions.

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