Discrimination between Atrial Flutter and Atrial Fibrillation by Computing a Flutter Index

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Abstract

We currently present the advanced development of our 12-lead ECG analyzing program HES. Recently our algorithm did not differentiate between atrial fibrillation or atrial flutter. Therefore, we now present a refined method for discrimination between atrial flutter and atrial fibrillation. The new approach contains two steps. In step one an algorithm has been developed that detects 'sawtooth'-like atrial flutter waves within a one second ECG data interval. This algorithm uses frequency domain measures after preprocessing the recorded data. The second step summarizes the results of step one applied to all 1s data segments by computing an atrial flutter index. The combination of step one and step two raises the total accuracy of the classification from 79.7% to 84.5%. The new algorithm was validated in 187 12 lead 10s resting ECGs, which were classified by an experienced cardiologist.

1. Introduction

Atrial flutter (AFL) and atrial fibrillation (AFIB) are very common abnormal rhythms, which constitute more than 8% of hospital ECGs [1]. In contrast to the normal sinus rhythm, at which a single electrical activation wavefront propagates from the sinus node via the atria toward the ventricles, AFIB is exhibited by multiple wandering waveforms with different propagation patterns [2]. However, the exact mechanism behind AFIB remains uncertain [3]. AFL is caused by a reentrant wavefront (=singular source) circulating in either the right or the left atrium [4]. Typical AFL waves are the 'sawtooth'-like uniform shaped patterns. For precise treatment (radiofrequency ablation vs. antiarrhythmic therapy) discrimination between AFL and AFIB is crucial. Because of the reentrant nature of AFL, it is possible to ablate the circuit that causes AFL. This is done in the electrophysiology laboratory by creating a linear lesion of scar tissue that crosses the path of the circuit that causes AFL. In AFIB, however, antiarrhythmic therapy and cardioversion are still the cornerstones of current therapy, although radiofrequency ablation of triggers in the pulmonary veins and substrate modification in the left atrium become increasingly important therapeutic strategies. Although AFIB and AFL rhythms have different generating mechanisms in the atria, they are often misclassified on the surface ECG by computerized algorithms because:

a) flutter and fibrillation waves can co-exist within the typical 10s resting ECG record. This results in "atrial flutter-fibrillation" patterns [5];

b) detecting atrial rhythm is difficult due to overlying QRS complexes and T waves [6]. This is specially true at high ventricular rates.

A technique that has been successfully used to detect atrial rhythm is the subtraction of QRS-T. Subsequently, the interval from QRS onset until T offset of an averaged median cycle is subtracted from the original ECG data, leaving the atrial activity as residual signal. This technique has been applied for atrial activity detection [1, 7-9] and for ECG data compression [10].

In previous studies the use of frequency domain measures after QRS-T subtraction has been applied [6,11-13]. Our approach is to create an algorithm, that:

- subtracts a median beat to get a residual ECG record pre-processing
- uses frequency domain measures for 1s ECG data intervals to detect atrial flutter waves
- results in an AFL index for the whole ECG record to classify AFL, mixed AFL/AFIB and AFIB.

The focus of the present study is to refine the classification AFL/AFIB, because the classification of AFL/AFIB is crucial for current optimised electrophysiological therapy.

2. Methods and material

2.1. Database

The database used for the method includes 187 resting ECG data (duration 10s, 12 leads), recorded with 500 Hz using a patient box from SCHWARZER. All ECG data are selected by a fibrillation/flutter detecting algorithm, which was implemented within the HES resting ECG analysis program. This algorithm uses the following parameters to detect AFIB/AFL:

- number of different P wave patterns,
- mean and std. of P wave correlation coefficient,
- RR interval sequences.

The data set contains 16 ECGs with typical AFL and 171 ECGs with AFIB. These ECGs were classified by a cardiologist applying criteria set up by a Joint Expert Group of European and American cardiologists and electrophysiologist for typical AFL[14]:

- atrial cycle length ≥ 190 ms (≈ 5.3 Hz)
- regular atrial depolarizations without isoelectric baseline between deflections
- monomorphic depolarization

2.2. Preprocessing before spectral analysis

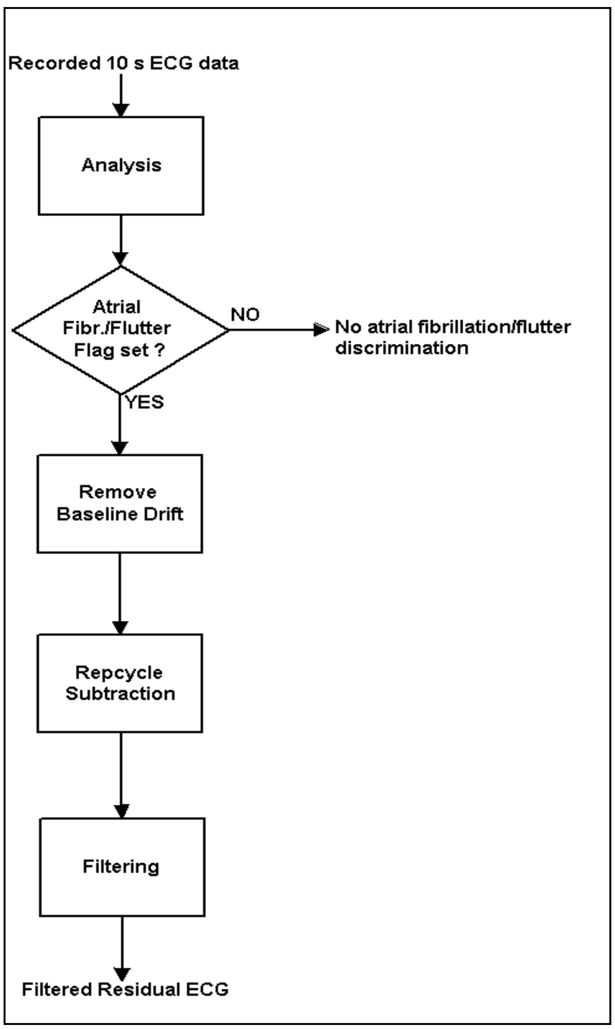

Fig. 1: Preprocessing before spectral analysis

Figure 1 depicts the scheme of signal preprocessing after ECG recording:

- Step 1: Analysis of the ECG data, containing beat localization, beat typing, computing an average repcycle and setting or resetting a fibrillation/flutter flag. If this flag is reset, no discrimination for AFIB or AFL will be done.
- Step 2: Removing baseline drift, using spline interpolation between the QRS onset of each single beat.
- Step 3: Subtracting the averaged repcycle from QRS onset until T offset of each QRS complex of dominant beat type. If a beat is a VES, QRS and T will be replaced by a straight line.
- Step 4: Line frequency, low pass filtering and limitation filtering will be done to prepare the ECG data for frequency analysis.

Figure 2 depicts an example of the first 5s ECG data in V1 before and after step one until step 4 of the preprocessing.

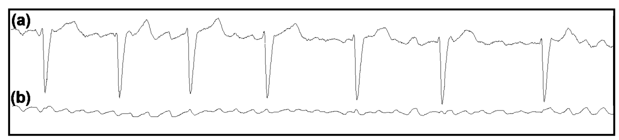

Fig. 2: Example of an ECG (a) before and (b) after preprocessing

2.3. Computing spectral parameters

The preprocessed residual ECG data (see 2.2.) are divided into 10 data intervals of 1s duration. For each 1s data interval for leads II and V1 a discrete Fourier analysis is applied after subtraction of the mean value to avoid a DC component in the resulting spectrum. This part is implemented within MATHLAB and results in a matrix of the power density for each 1s ECG data for each lead. Because of the 1s ECG data interval, the frequency resolution of the power spectrum is 1 Hz (= 60/min.).

The fundamental atrial frequency f_0 is computed for each lead and each 1s interval by searching for the maximum power density from 3 Hz to 10 Hz. The first ($f_1=2*f_0$) and the second ($f_2=3*f_0$) harmonic atrial frequencies are multiples of the fundamental atrial frequency.

2.4. Detecting atrial flutter waves

To develop an algorithm for detecting AFL waves within a 1s ECG data interval the data set of 187 ECGs is divided into a learn set (94 ECGs) and a test set (93 ECGs). For each ECG one 1s ECG interval is selected, which is validated as typical AFIB or AFL waves. The distribution of AFIB and AFL waves within learn and test set is homogenous. A linear discriminant analysis selects the statistic relevant parameters and the coefficients for the classification:

- the fundamental atrial frequencies f_0 for leads II and V1,
- power density at f_0, f_1 and f_2 in V1.

2.5. Computing the atrial flutter index

Applying the discrimination coefficients from 2.4 results in a probability value for AFL for each 1s ECG data interval. If the probability for AFL is larger than 50%, the respective data interval is classified as AFL. The AFL index is computed as number of AFL intervals divided by the number of total intervals (e.g. 10). For the whole 10s ECG data a mean probability for AFL and the standard deviation is calculated. The threshold for AFL index is selected by using the receiver operating characteristic (ROC) in figure 3. This figure depicts:

- Sensitivity and specificity for each possible single threshold (solid line with data points).
- AFL index of each possible threshold for AFL is depicted as one diamond within the curve.
- The dotted line depicts the sensitivity and specificity for randomised AFL/AFIB discrimination.
- The area between the solid line and the dotted line characterise the performance of the algorithm.
- The arrow marks the selected threshold of the AFL index (at 60%), because it is the nearest point of the solid line to the "optimal" discrimination, which is at the top left corner.

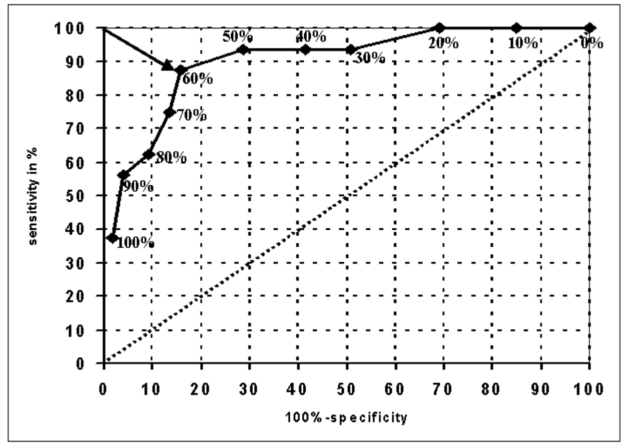

Fig. 3: Receiver operating characteristic (ROC) for discrimination between AFL and AFIB using a AFL index.

3. Results

Figure 4 depicts three representative examples of different AFL/AFIB ECGs. The respective ECG data of lead V1 are displayed and separated in 10 1s data intervals. For each data interval the AFL probability and the decision AFL waves detected or not are printed out. For each ECG the calculated AFL index and the mean/ std. for AFL probability are shown. The three examples are:

(a) atrial flutter ECG
(b) atrial flutter-fibrillation ECG (ECG with temporary atrial flutter waves)
(c) atrial fibrillation ECG.

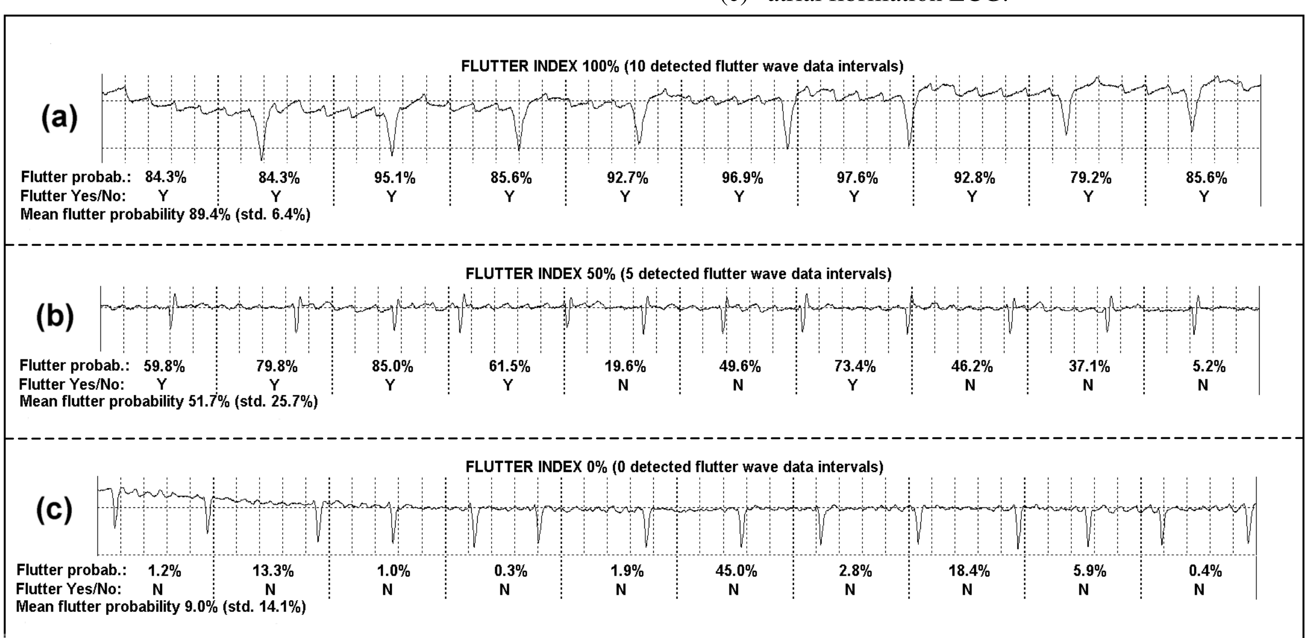

Fig. 4: Examples of lead V1 of three 10s ECGs. a) Atrial flutter ECG b) ECG with temporary atrial flutter waves and c) Atrial fibrillation ECG without flutter waves.

The results distributed for the learn and the test set for detecting AFL waves within a 1s ECG data interval are listed in table 1.

Table 1. Results and classification performance of the AFL wave detection algorithm.

Content	Learn set	Test set
1s ECG intervals	94	93
AFL	48	47
AFIB	46	46
True AFL	37	34
False AFL	6	8
True AFIB	40	38
False AFIB	11	13
AFL sensitivity	77.1%	72.3%
AFL specificity	87.0%	82.6%
Total accuracy	81.9%	77.4%

Using a threshold of 60% for the AFL index (see Fig. 3) the following results are obtained:

- total accuracy: 84.5%
- AFL sensitivity: 87.5%
- AFL specificity: 84.2%
- Positive/negative prediction value: 34.2%/98.6%

A better positive prediction value (PPV) is reached if the threshold for AFL is set from 60% to 100%. In this case the PPV raises from 34.2% to 66.7% while the NPV decreases to 94.4 %.

Due to the small number of only 16 AFL ECGs (9% AFL), the data set has not been divided into Test and learn set.

4. Discussion and conclusions

The proposed method for a refined classification between AFL and AFIB within the HES analysis program summarises the results of the frequency analysis of multiple ECG data intervals into an AFL index, which will be used for AFL/AFIB classification. The AFL index itself indicates the relative frequency of AFL waves within a recorded ECG. Computation of an AFL index increases the performance of AFL/AFIB classification compared with the pure AFL wave detection in sensitivity (72.3%→87.5%), specificity (82.6%→84.2%) and total accuracy (77.4%→84.5%). The negative predictive value (NPV) is high (98.6%) but the positive predictive value PPV (34.2%) is low. This is due to the small number of AFL ECGs in the data set. An adjustment of a better threshold of the AFL index for AFL increase the PPV significantly (34.2%→66.7%), but this would decrease the AFL sensitivity to unacceptable 40%.

In addition, the described method is easily applicable to computerised algorithms, because only well-established methods (e.g. filtering, Fourier Transformation and Median beat subtraction) are applied.

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