Automated ECG Diagnosis of Atrial Flutter by Means of Wavelet Transform

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Abstract

We report a new algorithm for the automated diagnosis of atrial flutter (AF) by computer ECG programs. It consists of applying the technique of wavelet transform (WT) to the detection of atrial flutter waves in the inferior lead Y of the Frank orthogonal ECG. The algorithm was developed and tested on a learning group of 325 cases with 47% of AF. Its clinical usefulness was prospectively assessed on a testing group of 1344 patients with 1.8% of AF. The sensitivity in this testing group was 44%. It raised to 80% by including the diagnostic statements of "possible AF", but at the same time the positive predictive value decreased from 84.6% to 66%. However, the specificity remained quite high : 99.2%. This WT procedure allowed to improve the performance of the automated diagnosis of AF as compared with our previous experience.

1. Introduction

Automated arrhythmia analysis remains the Achille's heel of ECG computer programs. Complex arrhythmias are usually misdiagnosed and only "simple" rhythm abnormalities are correctly diagnosed by most computer programs. Fortunately, normal sinus rhythms and a few simple rhythm abnormalities represent the vast majority of rhythm conditions encountered in daily practice. Among arrhythmias, the automated diagnosis of atrial flutter has been sofar a frustrating experience. Although the eyeball recognition of "flutter waves" or "F waves" is usually straightforward, at least for the experienced electrocardiographer, the automated diagnosis is more difficult. The detection of the flutter waves can be hampered by baseline drift and variable aspects of the F waves. In the rhythm analysis of the Louvain VCG program [1,2], there is an algorithm for the diagnosis of atrial flutter but the results were unsatisfactory because of a substantial number of false negatives and also of false positives. In this paper we report an attempt to improve the automated diagnosis of atrial flutter by applying the technique of Wavelet Transformation.

2. Material and methods

2.1 The Wavelet Transform

The Wavelet Transform (WT) is a particular set of band-pass filters. Its mathematical foundation was developed in the mid-eighties by J.Morlet & al., but other groups were working at about the same time on the same matter [3]. Simply stated, if we compare Fourier Transform (FT) with Wavelet Transform (WT), FT gives results only in the frequency domain, whereas WT performs a frequency analysis without discarding the time domain. At the origin, WT was used by geophysicists, but nowadays it is being applied in various areas such as speech processing, video image recognition, sonar and radar technology etc...In Cardiology, application of WT to the detection of late potentials has been attempted by D.Morlet [4] and O.Meste [5]. Other possible applications of WT to ECG analysis are sometimes theoretically described, but do not seem to be used in practice. Among the numerous basic functions of WT introduced since its discovery, we selected the original function described by J.Morlet [6], the complex sinusoid windowed by a gaussian envelope.

$$h(t) = e^{j\omega_0 t} \cdot e^{\frac{-t^2}{2N}}$$

Since digitized ECG data are no longer continuous variables, we must use the Discrete Wavelet Transform (fig 1). DWT is the convolution of the data and two limited series of coefficients, one real and the other orthogonal, the amplitude being the quadratic sum of the two parts. Applied in that manner, we could not find any valuable discriminant function for the detection of atrial flutter. By computing only the real part of the DWT, we were able to find a set of discriminant factors.

2.2 Application of DWT to the ECG

Clinicians and electrophysiologists have described

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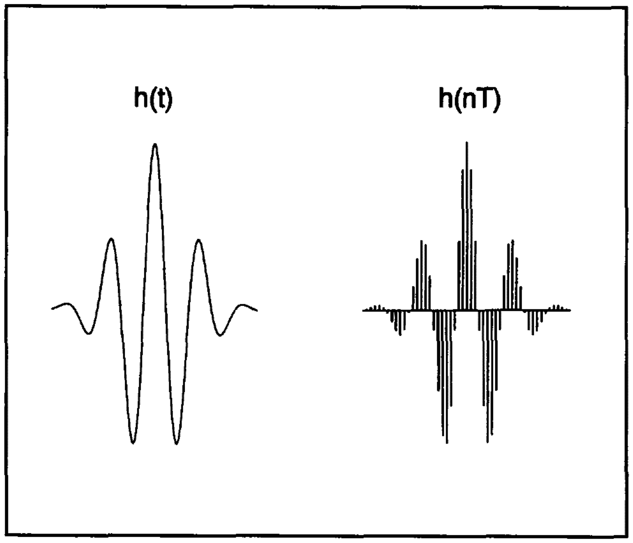

Figure 1 : Typical basic function of continuous and discrete Wavelet : h(t) and h(nT), respectively

different types of atrial flutter (fig 2). The "type I" (classic or common form) is the more frequent: the atrial rate is between 250 and 350 bpm, often very close to 300 bpm, and it displays the well known "saw-tooth pattern" in the inferior leads (II, III, aVF of the 12 lead ECG and lead Y of the Frank orthogonal ECG). This "common" atrial flutter is thought to originate from a circus movement of the excitation front going in a counterclockwise direction in the low right atrium, which explains why the negative part of the flutter wave is more prominent than its positive part in the inferior leads. The "atypical" or "uncommon" form displays a slower rate, between 250 and 300 bpm and the F waves are less negative in the inferior leads. In this case, the circus movement usually goes in clockwise direction in the low right atrium. Some authors have described another "type II" atrial flutter where the rate is faster, between 350 and 450 bpm, probably being related to an automatic focus instead of a re-entry circuit [7,8]. Even a "common" or "classic" atrial flutter can have different aspects if the atrial rate is decreased by medications or in the case of a "degenerative" atrial flutter on the verge of converting itself into an atrial fibrillation. Our algorithm was developed to fit the description pattern of the F waves in the type I atrial flutter, i.e., a period of 200ms or 5Hz. It was applied to lead Y which is the only inferior lead of the Frank orthogonal system. The baseline drift of the 10 second record of lead Y sampled at 500/s is first corrected, than all the QRS complexes are removed. To avoid the large number of floating point multiplications needed for the computation of DWT, a digital filtering at 12.5Hz is undertaken, followed by a reduction of the number of samples by a ratio of 1/10. On that reduced sample set, the real part of two DWTs centered on 5 and 10Hz is computed.

2.3 Detection criteria

Although each flutter wave cannot be located, a set of discriminant measurements could be identified, based on the mean heart rate and its variance, as well as on some measurements on the 5 and 10Hz DTW, e.g., the ratio of the number of peaks, the mean amplitude of the peaks, the maximal peak at 5Hz, etc... Thirteen discriminant criteria are applied in a particular sequence to qualify each ECG as "Flutter", "Possible flutter" or "Non Flutter". The atrio- ventricular ratio is also computed. Additional criteria are used in order to increase or decrease the probabilistic assessment of the flutter detection. Such non-Wavelet measurements include, for instance, the number of P or pseudo-P waves and their amplitude histogram on the raw data of lead Y.

2.4 Study population

The study population consisted of two groups of patients.

The learning group included a total of 325 cases which can be subdivided into two distinct series. A first series was composed of 172 cases including 43 atrial flutters and 129 sinus rhythms and other rhythm conditions, acquired from 1991 to 1993, used to develop the method and criteria. Another series contained 153 cases, including 109 atrial flutters, selected from 1981 since 1989 and mainly composed of false positives and false negatives diagnosed by the previous algorithm of the Louvain VCG program [2]. This series was used to test and improve the criteria.

The testing group consisted of a prospective series of 1344 unselected cases, consecutively collected from our hospital population and analyzed by the Louvain program from april to september 1994. This group includes 25 cases of atrial flutter, 71 cases of atrial fibrillation and 1248 other rhythm conditions of which a majority of sinus rhythms. It was used to assess the performance of the new algorithm on a daily routine basis.

3. Results

Tables 1 and 2 show the results of the analysis on the learning and testing groups, respectively. Because some cases of atrial fibrillation, especially "coarse" atrial fibrillation can be misleading as they closely resemble flutter waves, this condition is especially indicated. The category "Other" encompasses all other rhythm conditions, including a majority of sinus rhythms. Table 1 shows the results of the automated diagnosis of atrial flutter by WT on the learning group. In this group, the prevalence of atrial flutter was 46.7%. The sensitivity

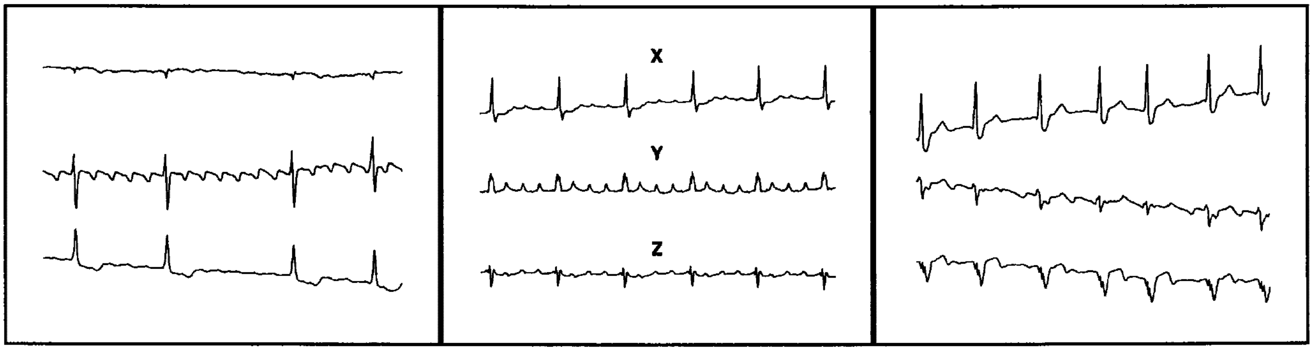

Figure 2. Type I atrial flutter (classic or common form) : atrial rate is 280 bpm and there is a "sawtooth pattern" in lead Y, with mainly negative F waves and no interspersed isoelectric segment.

Atypical or uncommon form of atrial flutter : atrial rate is 300 bpm but the atrial waves are mainly positive in lead Y.

"Degenerative" type I atrial flutter : atrial rate is 200 bpm, being decreased because of medications. The "sawtooth pattern" is much less evident although the atrial waves remain mainly negative in lead Y.

was 63.1% and the specificity 97.7%. By including the 27 cases of "possible atrial flutter" as a correct diagnosis, the sensitivity raised to 80.9%. The positive predictive value was 98% with only the "definite" statement and 96.8% with both "definite" and "possible" statements. The negative predictive value was 85.3%. Table 2 shows the results obtained on the testing group. Reflecting the rather low occurrence of atrial flutter in a general hospital population, the prevalence was 1.8%. The sensitivity was 44% with only a "definite" statement for atrial flutter, 80% by accepting both "definite" and "possible" as correct diagnosis. The specificity was 99.2%. The positive predictive value was 84.6% with "definite", 66% with both "definite" and "possible" statements, and the negative predictive value was 99.6%.

4. Discussion

The learning group contains an artificially high number of cases with atrial flutter, and accordingly, the predictive value of the automated diagnosis was high : over 95%. By including the "possible" atrial flutter statement, the sensitivity rose from 63.1 to 80.9% without affecting too much the positive predictive value. As there were only 4 false positives, the specificity was quite high, almost 98%. In this learning group, there was a majority of 114 cases with the common type I atrial flutter, of which 10 cases had a low atrial rate because of slowing by medication, 20 uncommon types and 18 cases with intermittent or degenerative atrial flutter on the verge of being transformed into atrial fibrillation.

Table 1. Learning group for the automated diagnosis of atrial flutter

Automated Diagnosis	Clinical Diagnosis			
	A.Flutter	A.Fibril.	Other	Total
A.Flutter	96		2	98
Possible A.Flutter	27		2	29
A.Fibril.	8	20	2	30
Possible A. Fibril.	4	1	2	7
Other	17	2	142	161
Total	152	23	150	325

Table 2. Testing group for the automated diagnosis of atrial flutter

Automated Diagnosis	Clinical Diagnosis			
	A.Flutter	A.Fibril.	Other	Total
A.Flutter	11		2	13
Possible A.Flutter	9		8	17
A.Fibril.	1	64	3	68
Possible A. Fibril.		1	1	2
Other	4	6	1234	1244
Total	25	71	1248	1344

The results obtained on the testing group represent the performance of the automated diagnosis of atrial flutter by WT in real life conditions. Because of the low prevalence of atrial flutter (less than 2%), the positive predictive value was, as expected, lower than in the learning group (84.6 vs 98%). The sensitivity was also lower (44% vs 63%). By taking into account the "possible" statement, it raised to 80% while the predictive value decreased to 66%. Because of the low number of false positives relatively to the total population, the specificity was quite high: 99.2%. These results show substantial improvement of the automated diagnosis of atrial flutter by WT, as compared with our previous experience [2]. The criteria leading to the diagnosis labelled "possible" atrial flutter were intuitively well weighted in order to give a probability of correct statement around 50%, i.e., 9 true positives and 8 false positives in the testing group. The WT algorithm was tailored to fit the classical type I pattern of atrial flutter. Hence, its performance will be less satisfactory with other types like "uncommon" flutter with positive F waves in inferior leads and type II atrial flutter with rapid atrial rate, or after slowing the atrial rate by medications or in degenerative forms very close to atrial fibrillation. In some rare instances, a false diagnosis can still be made when large sinus P waves have similar shape to the T waves and fall in such a position that they form together a 5Hz cycle.

5. Conclusion

The Wavelet Transform procedure allowed us to improve the performance of the automated diagnosis of atrial flutter by the Louvain computer program. However, because of its complexity, the procedure could prohibitively lengthen the computing time if applied to a slow system not equipped with a mathematical coprocessor.

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