Characterization of Atrial Tachyarrhythmias by Means of Time Frequency Analysis

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Abstract

Paroxysmal atrial fibrillation, atrial flutter and atrial tachychardia are all atrial tachyarrhythmias whose behavior, evolution and activation mechanism are under analysis.

Time-frequency analysis applied to an estimation of the atrial signal allows the characterization of tachyarrhythmia signal on frequency and time domain. In addition, the selection of a set of frequency parameters and a statistical evaluation make possible the definition of patterns which describe the typical behavior observed.

Our methodology has been applied in a blind manner in Holter monitoring database formed by 60 episodes which belong to 25 patients. We have found 49 episodes of abnormal rhythms with a mean duration of 79.8.

The results are the definition of three patterns: one of flutter (15 cases), and two distinct patterns during PAF: a chaotic one (23 cases) and a very uniform one (11 cases).

1. Introduction

Atrial tachyarrhythmias have been the main objective of important studies for years because of their incidence on population and the existing uncertainty with the underlying physiological mechanism. In particular, paroxysmal atrial fibrillation (PAF) and atrial flutter (AFL) are the most common arrhythmias. In fact, atrial fibrillation (AF) is suffered by as many as 5%-6% of those over age 65. Atrial tachycardia (AT) occurs in approximately 1 out of 1000 people (over 50 years old principally) [1]. In addiction, atrial tachycardia is often a precursor of atrial fibrillation and on physical examination may actually be confused with atrial fibrillation, since an irregular ventricular response can be noted. Therefore the analysis of the PAF signals is complex.

The most widely accepted theory of AF mechanisms was proposed by Moe [2] as early as 1962. It postulated that AF perpetuation is based on the continuous propagation of multiple wavelets wandering throughout the atria. Mapping of experimentally induced AF in canine hearts provided the first evidence supporting Moe's multiple wavelet hypotheses. Although all these studies have provided further insight into the electrophysiological mechanism underlying AF its clinical utility is limited by the need for invasive recordings. Latterly, several studies were proposed for two different purposes: quantify atrial fibrillatory frequency from the surface ECG using Fourier analysis and quantitatively subdivide AF [3] and atrial flutter among different rhythms from the surface ECG [4].

This kind of tachyarrhythmia has showed to have a particular P-wave that is reflected on the spectrum as a main peak around an abnormal frequency between 4 and 7 Hz. In the case of atrial fibrillation and flutter the P wave is replaced with a wave called f-wave [5]. The shape and rhythm of the f-wave have different influence on the spectrum according to the type of arrhythmia.

Since the atrial and ventricular activities overlap spectrally, linear filtering techniques are not suitable for extraction of the fibrillatory signal from the surface ECG. Frequency analysis of the surface ECG requires subtraction of the QRST. There are several techniques for this subtraction. The basic method calculates an average QRST and substrates for each complexes of the ECG [6]. Its advantage is to allow the extraction from only one lead, in an easy way. But the average QRST method does not adapt to the signal variations and the remaining ECG ventricular signal masks the atrial signal. Several methods are developed to resolve this problem like blind source separation, neural networks, separate QRS complex and T wave template subtraction, principal component analysis and the spatiotemporal subtraction [6-9].The process selected must adjust to each type of signal and the limitations on the number of leads as well as register's length.

The method proposed in this paper has been designed using a learning database with atrial tachyarrhythmia and similar features to the evaluation database. Time-frequency distribution has been used in order to characterize the signal tachyarrhythmias and to select criteria for the classification of the evaluation database.

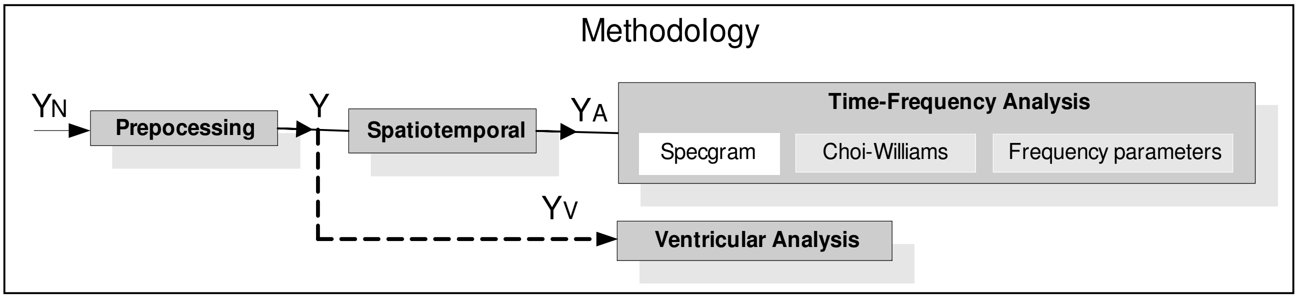

Figure 1. Methodology diagram where Y_N is the signal without preprocessing, Y the signal after preprocessing, Y_A the atrial signal estimation and Y_V the ventricular signal estimation

2. Databases

Two databases are being used in order to perform a blind analysis: a learning database and an evaluation database.

The learning signals are from MIT-BIH arrhythmia database (www.physionet.org/physiobank/database/afdb). This database is composed of 25 records of 24 hours monitoring Holter signals. Arrhythmias present are AFL and PAF episodes. Thus, it has been possible to evaluate the analysis method in order to adjust and define the atrial extraction algorithm, the spectral analysis and the frequency parameters.

The evaluation database has 60 episodes of monitoring Holter signals taken from 25 patients. Recordings have been selected by the arrhythmias unit of the HCUV because of paroxysmal palpitations. All of them have the presence of at least one non-sustained episode of atrial tachyarrhythmia, but this information is unknown to us because of the blind analysis.

The equipment used by the arrhythmia unit of the HCUV for monitoring patients is the Holter Synetech ELA MEDICAL (3 leads, 200 samples/second, 12 bits resolution). The bandwidth of these signals includes from 0.05 Hz to 75Hz.

3. Methods

The process consists of three fundamental phases: signal preprocessing, atrial activity estimation and atrial activity analysis. Figure 1 shows a schema of this sequential process.

Signal prepocessing consists of a highpass filter with a cut-off frequency at 0.5Hz, a lowpass filter at 25Hz and removing of the fluctuation of ECG baseline with the calculation of the baseline wander to be subtracted.

An accurate analysis of atrial activity is usually precluded by ventricular activity at the frequency domain. The QRST cancellation is necessary in order to identify the presence or absence of an abnormal atrial contribution. The atrial activity estimation is extracted from the ECG using the Spatiotemporal (ST) algorithm. This algorithm allows one an adapted extraction of morphological changes caused by axis rotation of the heart and adapts to the amplitude of each lead [8]. Besides, it is appropriate for tracking changes of rhythm which are very common in these types of signals and has the advantage of providing an atrial signal. The ST extraction method obtains satisfactory results with only few leads.

Atrial signal corresponds to an estimation of the atrial activity of the ECG signal during the entire interval and is analysed between 2.5 and 25Hz because the main peak and its principal harmonics are concentrated in this bandwidth.

The method provides one atrial signal for each lead. It is necessary to choose one lead to be analyzed but it is possible to contrast with another lead. The rest of the method is focused principally on the atrial signal analysis.

The analysis of atrial activity is done by means of time-frequency tools. The first step is to find the temporal beginning and the end of each type of arrhythmia at the records. Then atrial signal is filtered and downsampled from 200Hz to 50Hz. This step is possible because the bandwidth of interest is bordered between 2.5Hz and 25Hz. At the same time, this supposes a reduction of the processing cost for the time-frequency analysis and an elimination of signal out of interest which could introduce interferences on the spectrum. If the signal has not harmonics it is convenient to focus on a narrower band lower than 12 Hz.

Two time-frequency are applied: the Specgram is used to look for the episode temporal marks and the Choi-Williams for time-frequency analysis. Both are bilinear transforms with accurate precision.

Before the analysis, temporal transitions between different rhythms have been found using the Specgram transform. In this way, 49 segments of abnormal rhythm were found in the 60 episodes. Their mean duration is 79,8s with episodes between 2.5s and 622s.

Next, fundamental parameters are extracted after the Choi-Williams distribution are applied. The selected parameters are those which allow one to describe the spectral characteristics on each case so that these characteristics are sufficient for obtaining an accurate classification criterion. Some have been used for making a statistical treatment. These are principal peak frequency, bandwidth of the principal peak and the mean deviation of the main peak frequency in time. Other parameters are calculated and considered in the classification, such as the presence of absence of a harmonic of the main peak, the variation of the principal and secondary frequency and the variation of the principal and secondary peak amplitude.

Nevertheless the analysis can be completed with a brief review of a ventricular activity analysis.

Ventricular analysis can help to identify the types of rhythm in particular cases with the evaluation of heart rate variability or the analysis with time-frequency transforms. Thereby it is possible to include other views to the signal analysis.

4. Results and Discussion

The results are the classification of a blind database in three groups and their description by means of a set of parameters.

We have found 49 segments of several arrhythmias among the 60 episodes. These are one of flutter (15 cases), and two distinct patterns during PAF (34 cases): a chaotic one (23 of 34 cases) and a very uniform one (11 of 34 cases).

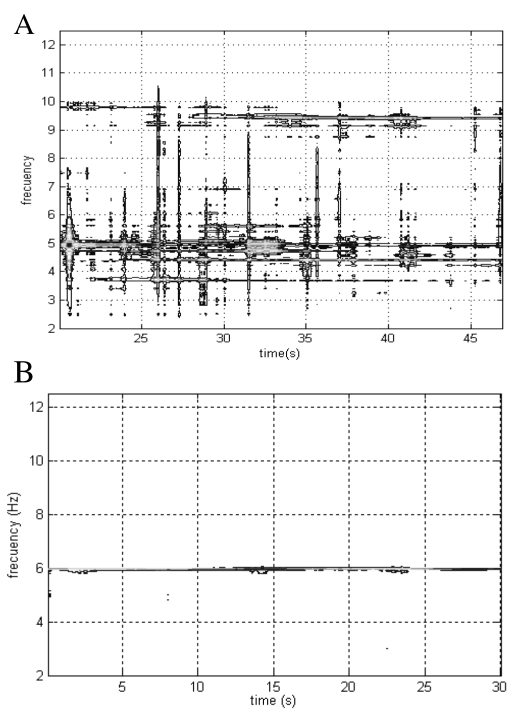

Figure 2: A) shows the time-frequency of the PAF for the pattern A and B) for the pattern B. The vertical axis corresponds to frequency in hertz and the horizontal to time in seconds.

The typical pattern of flutter has a main peak in the lowest range of frequency (4.44±0.52Hz) with a narrow bandwidth of 1.5±0.3Hz. The spectrum has one main peak which concentrate all the energy and usually has harmonics. The spectrum is more stable in time without changes in the principal frequency.

In PAF episodes, two patterns could be observed (see Figure 2). The pattern A is a distribution without a dominant mean peak formed by several contributions in frequency (5.05±0.7Hz) which increase their or loses their importance in a short time. Therefore, this chaotic distribution does not keep one main peak throughout the time and the main frequencies are scattered over a long range. There are 23 segments of this case. In this type, the bandwidth is the widest of the three patterns (2.37±0.8Hz).

Type B has a distinctive pattern with one clear main peak which concentrates the major part of the signal energy and goes on stable along time. This type has the higher frequency range (5.75±0.47Hz) and a narrow bandwidth of 1.7±0.3Hz. Flutter spectrum has similar characteristics to this type of PAF. Despite the main peak remains very stable, the peak has a tendency to soft raising with time that is showed on the spectrum. There are 11 segments of this type. These differences can be observed directly on the figure 2 B) and on the table 1.

The fundamental parameters which the analysis can provide us are related to the frequency description of the signal. Therefore, the results show typical frequency parameters for an atrial arrhythmia signal like the principal frequency, the bandwidth of the main peak and the mean deviation of the principal frequency in time.

Table 1: The fundamental parameters that have been selected to characterize the spectrum are the principal frequency, the bandwidth and the mean deviation of the frequency in time.

parameters	AFL	PAF-A	PAF-B
PF (Hz)	4.44±0.52	5.05±0.7	5.75±0.47
BW (Hz)	1.5±0.3	2.37±0.8	1.7±0.3
Dev. PF (Hz)	0.6±0.4	0,8±0.48	0,16±0.17

These main parameters have been analyzed with the ANOVA test that provides the results shown on table 2. The parameters has a homogeneous variance (Levesne statistic is higher than 0.05) and a normal distribution (Kolgomorov-Smirnov statistic is higher than 0.05). Therefore, ANOVA test show us that the differences between the main frequency parameters which are statistically significant in all cases except between the type B of the PAF patterns and AFL in the cases of deviation principal frequency and main peak bandwidth.

The ANOVA test on the second type of PAF and AFL bandwidth renders non-significant differences. This is a logical result due to the similar characteristics of the shape of the spectrum in the PAF-B pattern and in the

AFL pattern. In the same way, the deviation of the principal frequency is not a significant parameter for distinguishing these cases due to the reduced variation of these types of signals.

Table 2: The table shows the results of the multiple comparisons of Scheffe for the ANOVA test parameters of the table 1.

p value	AFL vs PAF-A	PAF-A vs PAF-B	PAF-B vs AFL
PF	0.006	0.03	4.13E-06
BW	8.06E-05	0.012	0.61*
Dev. PF	0.0005	1.84E-05	0.981*

* statistically non-significant

In both, there is only one main peak which concentrates all the energy of the signal on a narrow bandwidth. Besides, the main peak is very stable and it hardly has variations around the main peak. In case of PAF-B pattern usually the peak increases in time but with a low variation. These similar characteristics make it difficult to distinguish PAF-B pattern from AFL pattern using only the bandwidth criterion. But this conclusion corroborate that some of the spectral features on AFL and the second type of PAF are common.

5. Conclusions

This methodology of analysis permits the extraction of parameters that significantly discriminate among different types of atrial tachyarrhythmias.

The characterization of the signal and the classification of a database in a blind manner have succeeded in the definition of three patterns of atrial signal spectrum. The PAF patterns bring up the question if these results show two behaviours for the paroxysmal atrial fibrillation (focus and no focus) or if the uniform pattern described a paroxysmal atrial tachycardia. Further studies are necessary to resolve this uncertainty because the three leads of Holter signal do not present the guarantees necessaries to know more about these recordings.

The ECG signal processing technique described allows the average frequency of fibrillatory activity to be quantified in time using the surface ECG. This measurement correlates well with intraatrial cycle length, a parameter which appears to have primary importance in the genesis and perpetuation of AF. Thus, determination of atrial fibrillatory frequency from the surface ECG may prove useful for non-invasive assessment of the electrophysiological state of the atria in patients with AF.

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