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5.1.2: Heart Rhythm and Pacing

Time-Frequency Methods for High-Resolution ECG Analysis

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Abstract - Spectro-temporal methods of High Resolution ECG analysis based on fast Fourier transform, autoregressive estimation and wavelet transform are discussed. Sensitivity of these methods were evaluated by analysis of 80 patients after myocardial infarction - 40 with sustained ventricular tachycardia and 40 without arrhythmia. To compare the results of all three methods quantitative parameters were calculated. The averaged values of these parameters were significantly different for patients with ventricular tachycardia compared to patients without arrhythmia. Sensitivity obtained in our study by wavelet transform (61%) was lower than for Fourier transform (81%) and autoregressive (73%) methods.

INTRODUCTION

Ventricular late potentials (LP) - low-amplitude high-frequency signals located at the end of the QRS complex and in ST segment, are relatively well documented risk marker of life-threatening ventricular tachycardia (VT) for patients after myocardial infarction (MI). The use of classical methods of high-resolution ECG (HRECG) analysis is limited because time-amplitude method proposed by Simson do not detect higher frequencies and typical frequency analysis do not allow for time localization of LP's. The best methods for late potentials detection are combined time-frequency methods allowing for spectral analysis with respect to their time localization in the signal. From various methods of spectro-temporal analysis the fast Fourier transform (FFT) and parametric modeling method with autoregressive estimation (AR) as well as wavelet transform (WT) were tested in our study. The aim of this work was to compare above mentioned methods and their sensitivity in detection of patients with high risk of ventricular tachycardia after myocardial infarction.

METHODS

ECG recordings were performed using three bipolar modified Frank leads according to commonly accepted international standard [1]. Signals were analog-to-digitally converted with 12 bits accuracy and then averaged from approximately 200 beats (noise level 0.3-0.7 μV).

In FFT method the spectra were estimated with a periodogram method [2]. To reduce the spectral leakage, Blackman-Harris four-term window function was applied. Before the estimation an DC offset was performed. A total of 25 data segments of 80ms length was analyzed. The first segment started 20 ms before the QRS end and the next spectra followed in 2ms step. As a result the three dimensional spectro-temporal map consisted of 25 spectra in frequency range 0-250Hz was obtained.

From spectro-temporal distribution the coefficient called Normality Factor (NF) was calculated [3]. For all spectra correlation coefficient to the last 25-th spectrum considered as reference was calculated in the frequency range 40-150 Hz. NF was calculated as the mean of the correlation coefficients of spectra 1-5 (expected LP's location) divided by the mean of the correlation coefficients of spectra 21-25 (reference noise) [3].

In autoregressive method the power spectrum density was estimated with a Burg algorithm. This algorithm was found to be the most proper for estimation of coefficients of the AR model. [6]. Based on analytical and empirical studies the model order of 5 was determined and applied. A total of 60 data segments of 25ms length with 2 ms step was analyzed and ploted in form of spectro-temporal map. Similarly to FFT method the first segment started 20ms before the QRS offset.

For quantitative evaluation of the spectro-temporal map in AR method the Spectral Factor (SF) was determined [6]. The SF was calculated as the mean of the area under the spectrum in the frequency range 40-150 Hz for spectra 40-50 (reference noise) divided by the mean of the area under the spectrum for spectra 15-40 (expected LP's location).

In wavelet method spectra were calculated with modified wavelet transform [2].The modified function of Morlet was applied with parameters: $\sigma_1 = 1.00$ and $\sigma_2 = 3.33$.
The wavelet transform was calculated in a frequency range 0-250 Hz for 100 ms data segment started 20 ms before the QRS offset in steps of 1 ms. Results were presented in form of spectro-temporal map.

To enable a comparison of results obtained using wavelet transform with those from FFT and AR methods a quantitative parameter describing the area under the map in the frequency range of 100-200 Hz for period 30-60 ms was calculated.

The analysis with all spectro-temporal methods was carried out for all three X,Y,Z leads. The values of NF for FFT method and SF for AR method below 30% were considered abnormal indicating the LP's presence [5,6]. In WT method the parameter values (area under the map) higher than 10000 were taken as abnormal.

Total 80 patients (pts) after heart infarction were analyzed

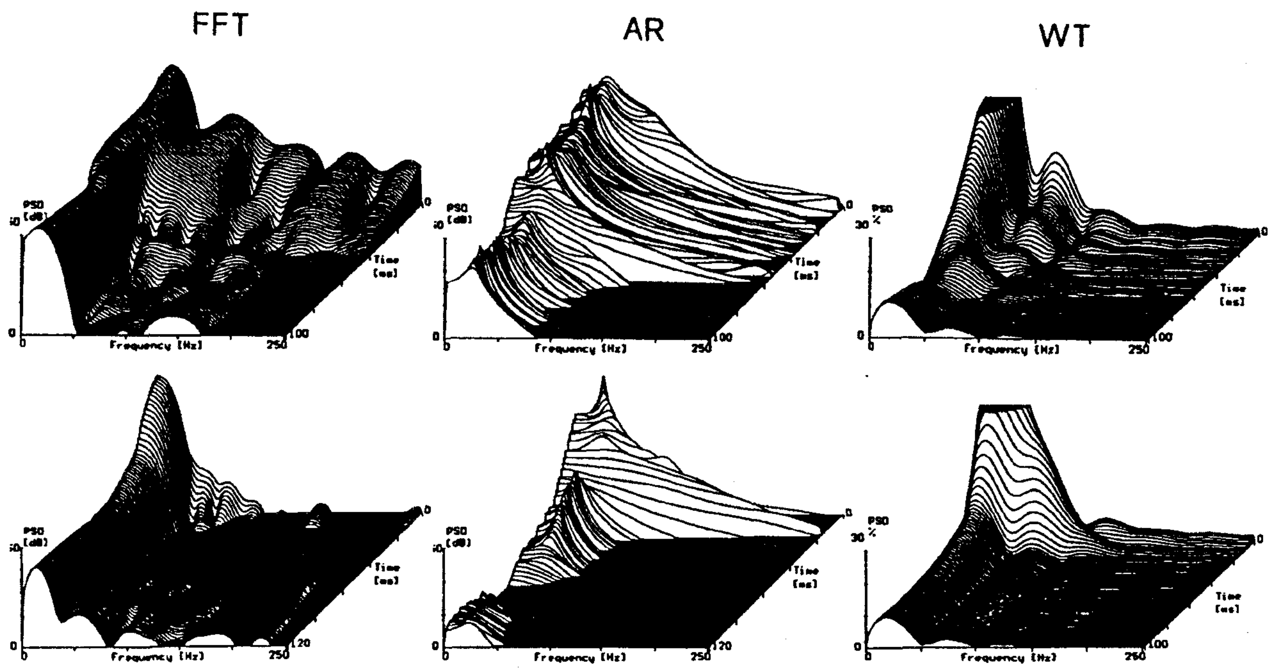

Fig.1 Spectro-temporal maps obtained by FFT, AR and WT methods for VT patient (upper) and patient without arrhythmia (lower row).

- 40 pts with documented sustained ventricular tachycardia and 40 pts without arrhythmias and circulatory insufficiency.

RESULTS

Results of analysis in form of 3-D plot for VT patient and patient without arrhythmia are presented in the Fig.1. For all three studied methods there is visible difference in spectral distribution in ST segment for patients with and without arrhythmias. The mean values of quantitative parameters for patients with and without VT were significantly different ($p<0.05$).

The results obtained from quantitative parameters allow for evaluation of sensitivity and specificity of these methods in detection of patients at risk of VT. Based on assumed criterion of LP detection for both spectral methods and for wavelet method following values of sensitivity and specificity were obtained:

	FFT	AR	WT
Sensitivity	81 %	73 %	61 %
Specificity	98 %	92 %	75 %

CONCLUSIONS

Spectro-temporal methods presented in this work allows for detection of patients prone to ventricular tachycardia. The differences in results for patients with and without VT in the 3-D maps are clear visible (fig 1). However the values of sensitivity and specificity of these methods are still not satisfactory. Calculated coefficients can be probably improved by some modifications of formula for factors determination. Further study are in progress .

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