Spectral Analysis of Life-Threatening Cardiac Arrhythmias

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The presented work is aimed at investigation of power spectra characteristics of ECG life-threatening cardiac arrhythmias by applying Fourier transform on 10 s ECG epochs. A total number of 240 ECG signal segments (selected from a large out-of-hospital ECG database to cover the variety of specific ECG waves, which appear for six arrhythmia categories) were involved into statistical analysis in order to assess the possibility for separation between shockable and non-shockable arrhythmia categories, using the calculated power spectra characteristics. Their combination with ECG morphology parameters could be a useful approach for improvement of the shock-advisory decision accuracy of automatic external defibrillators, in order to match the diagnosis of trained medical personnel.

Keywords: ECG arrhythmia, power frequency spectrum, ECG characteristics

1. Introduction

The reliable recognition and adequate electrical shock therapy of life-threatening cardiac states depends on the electrocardiogram (ECG) descriptors, which are used by the defibrillator-embedded automatic arrhythmia analysis algorithms. Our previous experience with real-time analysis of ECG morphology parameters and band-pass filter output parameters [1] proved that the value range of each parameter overlaps for the two general classification groups of shockable and non-shockable rhythms. More detailed analysis [2] demonstrated that this overlapping results from shared distributions of the parameter values for specific arrhythmias, which belong either to the shockable rhythms or to the non-shockable rhythms. Since we had recently studied a wide set of morphology parameters and several parameters extracted in a narrow frequency band, it was of interest to investigate the spectral characteristics of the different arrhythmia types in the whole range of spectral frequencies. The power spectrum of the ECG signal could provide useful information about the QRS complex and the other ECG waves (P, T, fibrillation). Thakor et al. [3] designed a band-pass filter with a central frequency at 17 Hz, which effectively detected the QRS complexes in the ECG signal. Minami et al. [4] studied the QRS frequency spectra in 4 Hz bands for classification of three arrhythmia types. Other authors [5,6] used the ECG frequency characteristics to apply wavelet transformations for detection of life-threatening cardiac arrhythmias. However, the achieved accuracy for making an adequate automatic shock advisory decision should be improved in order to match the diagnostic accuracy of trained medical personnel.

The presented study was aimed at assessment of the spectral characteristics of a wide variety of arrhythmia types in the whole range of spectral frequencies in order to investigate the possibility for better separation between shockable and non-shockable rhythms.

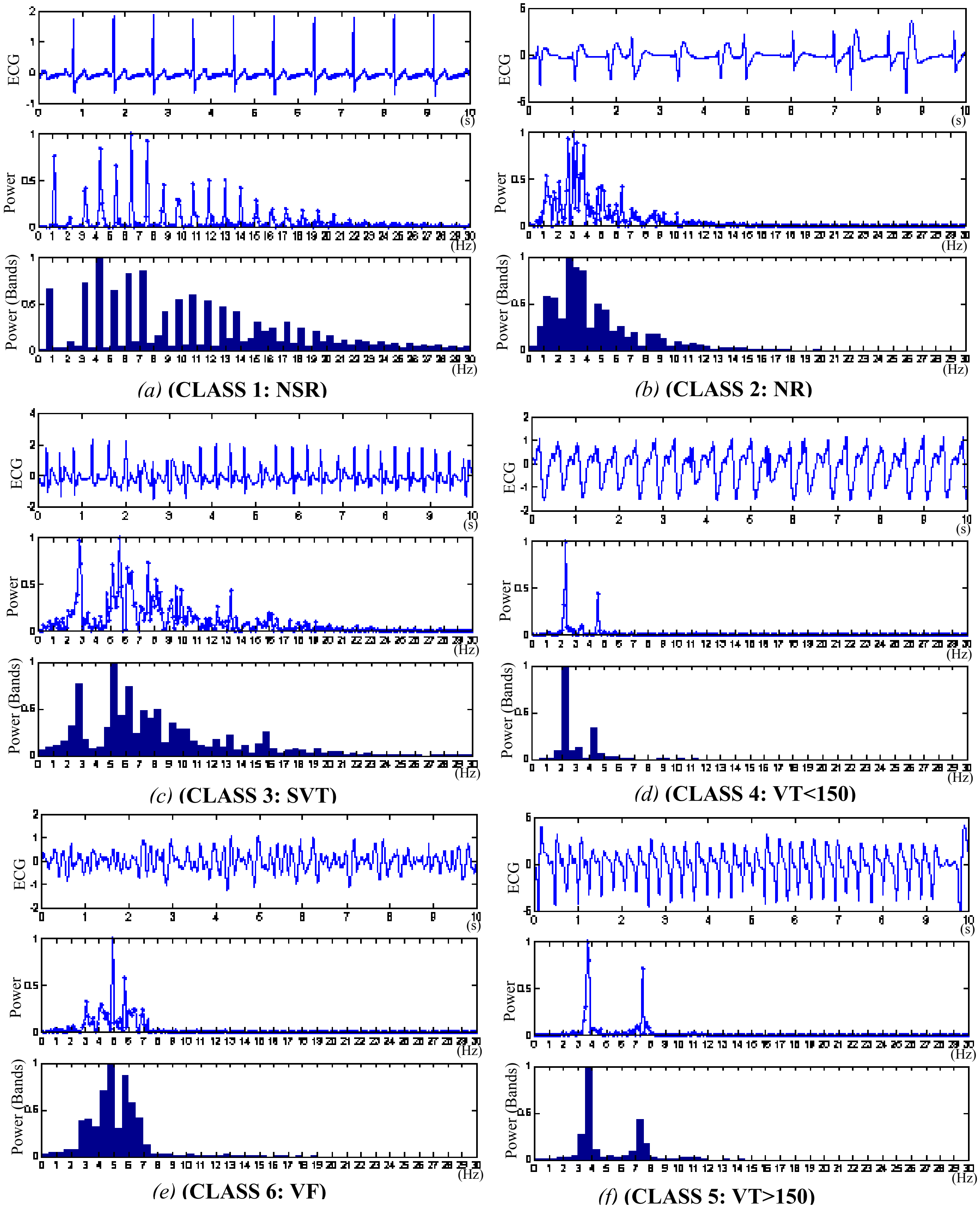

Fig. 1. Examples of 10s ECG signal segments, their Power spectra (PS), and the calculated Power Spectra in frequency bands of 0.5 Hz (BPS), for the defined 6 rhythm caregories: (a) CLASS 1: Normal Sinus Rhythm (NSR); (b) CLASS 2: Normal Rhythm (NR); (c) CLASS 3: Supraventricular Tachycardia (SVT); (d) CLASS 4: Slow Ventricular Tachycardia (VT<150); (e) CLASS 6: Ventrucular Fibrillation (VF); (f) CLASS 5: Rapid Ventricular Tachycardia (VT>150).

2. METHOD

2.1 ECG signals

The ECG signals involved into analysis were selected from a large database of ECG recordings, which were collected by trained paramedics during application of automatic external defibrillators (AEDs) in real out-of-hospital cardiac arrest incidents. The one-channel ECG signals were acquired through large self-adhesive electrodes placed in standard apex-sternum position for defibrillation. The standard analog filtering of AEDs was applied, with 1-30 Hz 'monitor-type' ECG bandwidth. The data were sampled at 500 Hz, 8-bit amplitude resolution and were stored in the PCMCIA cards available in AEDs. The wide varieties of cardiac arrhythmias were classified into six arrhythmia categories, which are listed in table 1. Each rhythm class is represented by 40 cases (with duration of 10s), selected to cover as much as possible the variety of specific ECG waves, which appear for this category. Thus a total number of 240 ECG signal segments were investigated.

CLASS	LABEL	SHOCK DECISION	RHYTHM TYPE	DESCRIPTION
1	**NSR**	Non-shockable	Normal sinus rhythm	P, QRS, T waves are visible
2	**NR**	Non-shockable	Normal rhythm	Premature atrial and ventricular contractions, atrial flutter and fibrillation, bundle branch blocks and bradycardias
3	**SVT**	Non-shockable	Supraventricular tachycardia	Tachycardia with supraventricular origin and rate above 120 bpm
4	**VT<150**	Non-shockable	Slow ventricular tachycardia	Tachycardia with ventricular origin and rate below 150 bpm
5	**VT>150**	Shockable	Rapid ventricular tachycardia	Tachycardia with ventricular origin and rate above 150 bpm
6	**VF**	Shockable	Ventricular fibrillation	Coarse ventricular fibrillation with amplitude above 0.25mV

Table 1. Description of the ECG rhythm classes involved into analysis.

2.2 Power spectra characteristics

By applying Fourier transform (FFT) on 10s ECG epochs we computed the signal power spectra (PS) and the summary power spectra in narrow frequency bands of 0.5 Hz (BPS). Fig.1 shows some examples of ECG signals, which are representative for the above defined arrhythmia types and their power spectra (PS and BPS). We defined the following characteristics of the normalized power spectra:

- *Max Peak Frequency* – the frequency of the maximal peak in PS;
- *Summary Power Residual after 10 Hz* – the sum of the spectral components above 10 Hz in BPS;
- *Max Frequency with Power above 0.1* – the maximal frequency, which corresponds to a level above 0.1 in BPS;
- *Summary Peaks Amplitude Ratio* $=\sum_{i=1}^{N-1}(A_{i+1}/A_i)$, where A_i is the amplitude of the sorted by amplitude peaks in BPS with index *i*; *N* is the total number of the peaks.
- *Number of Peaks* – the number of peaks above a level of 0.1 in BPS;

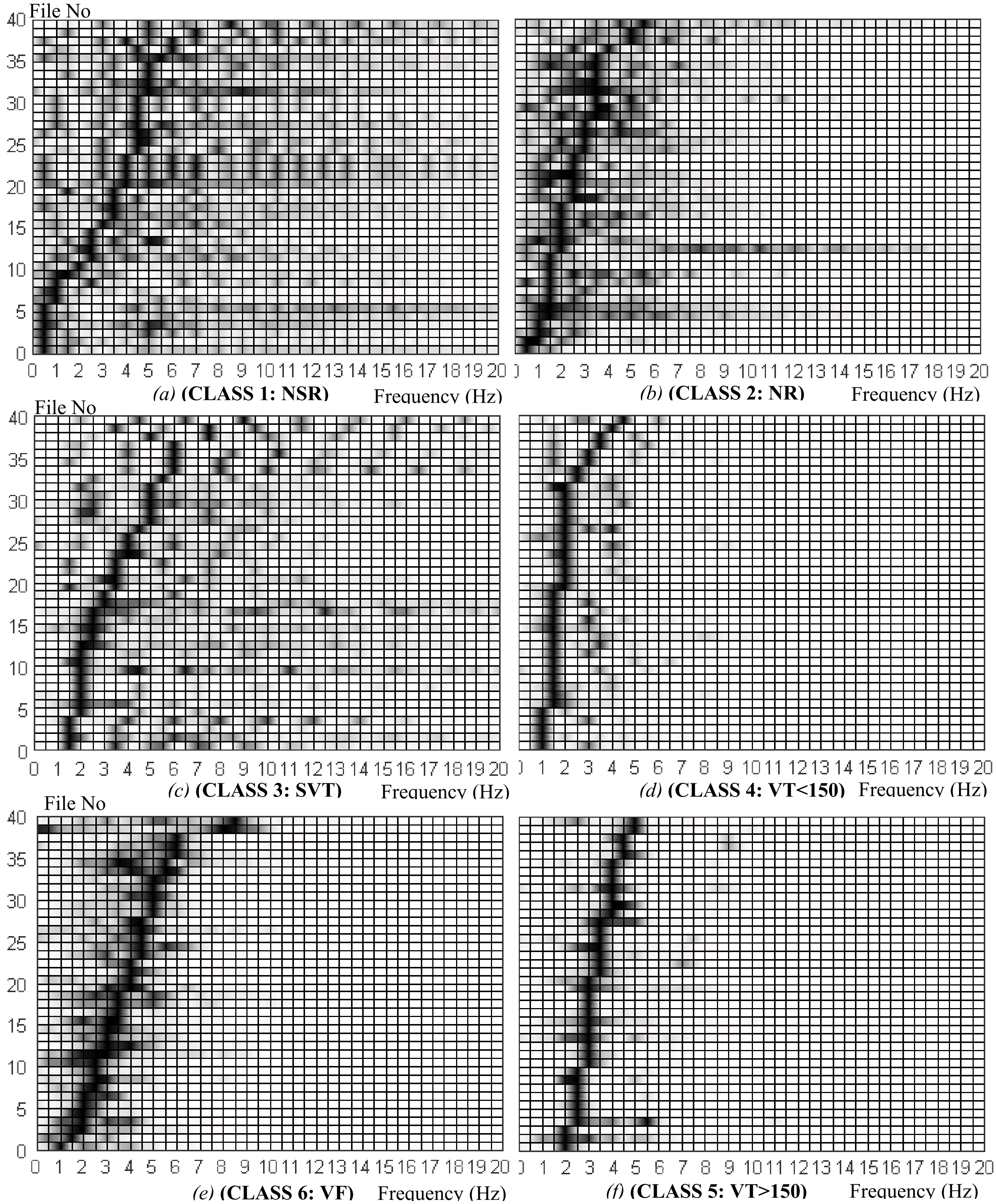

Fig. 2. Power spectrum map - The Power spectrum (estimated in frequency bands) represented for each file included in the study. All files are groupped in 6 arrhythmia caregories: (a) CLASS 1:(NSR); (b) CLASS2:(NR); (c) CLASS3:(SVT); (d) CLASS4: (VT<150); (e) CLASS6: (VF); (f) CLASS5: (VT>150).

3. RESULTS

The gray-scale maps in fig. 2 represent the normalized band power spectra (values between 0 and 1) for all files included in the study. All files are groupped in 6 rhythm classes (40 files for each class ranged on the Y-scale). The frequency bands of 0.5 Hz are marked on the X-scale up to 20 Hz, thus emphasizing only the significant frequency components of the ECG signals. The statistical results for the median value, 25% - 75% range around the median value and the entire range of the defined above power spectra characteristics are illustrated in fig. 3. Grouping by arrhythmia categories was applied. The characteristic '*Number of Peaks*' is represented in fig. 4 with histograms for the six rhythm classes.

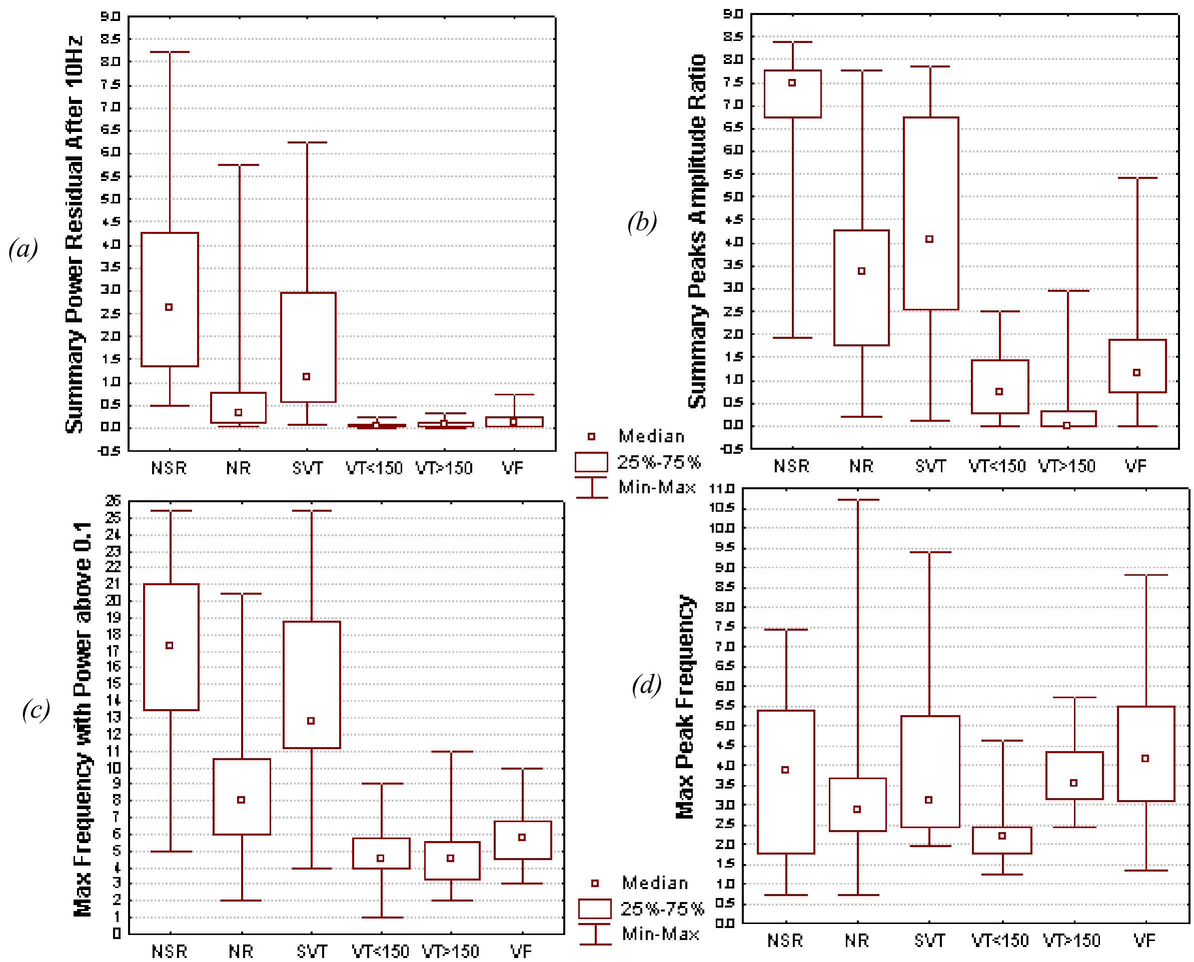

Fig.3. Statistical assessment of four power spectra characteristics in six rhythm classes.

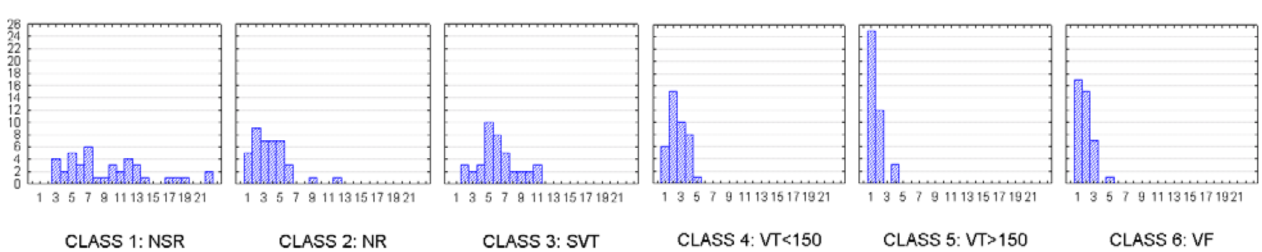

Fig.4. Histograms of the parameter 'Number of Peaks'

4. DISCUSSION AND CONCLUSION

The study proved that the different rhythm classes feature with specific power spectra, observable in fig. 1 and fig. 2. The NSR and SVT rhythms typically have narrow ventricular complexes at regular RR intervals, which lead to a broad range of frequencies in the power spectrum (above 10 Hz) with a number (more than 5) of well-defined peaks. The NR class contains rhythms with some kind of disturbances in the conduction path inside the heart, which results in wide and irregular ventricular complexes. They characterize with relatively broad spectral band, absence of both high spectral frequencies and well-defined peaks. The VT rhythms (slow and rapid) have wide and regular ventricular complexes, which are represented by a well-defined spectral peak with frequency corresponding to the heart rate. The VF rhythms have irregular waves, without ventricular complexes, which is associated with relatively broad frequency spectrum (below 10 Hz) with central frequency at the fibrillation frequency. The described power spectra features of the different rhythm classes are assessed by the defined in section Method characteristics. It is evident that the distributions of all characteristics are overlapping for the different rhythm classes (see fig. 3 and fig. 4), but their combinations could be used for effective separation of the arrhythmias in the two classes of non-shockable (NSR,NR,SVT,VT<150) and shockable (VT>150,VF) rhythms. Approximate threshold values of the power spectrum characteristics, which are applicable for recognition of the arrhythmias in the appropriate shock-advisory class are presented in table 2.

Power Spectrum Characteristic	**Non-Shockable Rhythms**				**Shockable Rhythms**	
	NSR	**NR**	**SVT**	**VT<150**	**VT>150**	**VF**
Summary Power Residual after 10 Hz	>0.75	>0.25	>0.5	-	-	-
Max Frequency with Power above 0.1	>11	-	>11	-	-	-
Number of Peaks	>5	-	>5	-	-	-
Summary Peaks Amplitude Ratio	>2	>2	>2	-	<0.25	-
Max Peak Frequency	-	-	-	<2.5	-	-

Table 2. Approximate threshold values of the power spectrum characteristics

The VF spectrum is overlapping with the characteristics of at least one non-shockable rhythm. However, an automatic arrhythmia analysis algorithm could use the proposed characteristics to detect the non-shockable rhythms and to consider the remaining rhythms for shockable. The spectral descriptors are suitable also for supplementary parameters in automatic shock-advisory algorithm.

5. REFERENCES

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