Estimation of Electrocardiogram Peak Frequency and Periodicity During Ventricular Fibrillation

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Abstract

The success of ventricular defibrillation depends on many factors, but the time elapsed from the fibrillation onset is most important. The aim of this study was to assess the ECG peak frequency and periodicity changes during ventricular fibrillation.

The fibrillation signal peak frequency decreased with elapsed time in N1=21 of the processed signals (62%). It fluctuated over a relatively constant value in the remaining N2=13 cases (32%). The leakage parameter increased with time in N3=15 of the assessed cases (44%), decreased in N4=2 (10%) and fluctuated over a relatively constant value in the remaining N5=17 (50%). The leakage increased in 57% of N1, fluctuated over a relatively constant value in 33% of N1 and decreased in 10% of N1. In 77% of N2, the leakage also fluctuated, and in the remaining 23% of N2 it increased.

Optimal timing for efficacious defibrillation shock might be looked for by methods for short-time (e.g. less than a few seconds) detection of rhythm organization.

1. Introduction

Early defibrillation of ventricular fibrillation (VF) increases the survival rate after cardiac arrest. Yakaitis et al. [1] reported that within 1 min after the onset of ventricular fibrillation, the rate of successful resuscitation was 100%. It decreased to 90% at 3 min and fell down to 30% after 5 min.

Small et al. [2] assessed the variation of the dominant ECG period during VF. Dzwonczyk et al. [3] suggested the usage of median frequency for estimation of the duration of cardiac arrest and determination of VF downtime. These two parameters were suggested to be a possible indicator of successful defibrillation [3, 4]. Eftestol et al. [5] analyzed the ability of four spectral features (centroid frequency, peak power frequency spectral flatness measure and a frequency band limited energy measurement) to discriminate between pre-shock ECG segments related to successful versus unsuccessful shocks.

The aim of this study was to assess the surface electrocardiogram (ECG) peak frequency and periodicity during VF.

2. Methods and material

2.1. Ventricular fibrillation signals

A set of 34 records from the American Heart Association (AHA) and the Massachusetts Institute of Technology (MIT) databases were used. Records longer than 5 min were selected. Eleven AHA database records (from 6 patients) were taken, one from the MIT Creighton University Ventricular Tachyarrhythmia Database and 22 (from 11 patients) from the MIT Beth Israel Hospital Malignant Ventricular Arrhythmia Database. Each record was initially preprocessed by i) a notch filter to virtually eliminate powerline interference, ii) a 1 Hz cutoff frequency high-pass filter to suppress residual baseline drift, and iii) a second-order 30 Hz cutoff frequency low-pass Butterworth filter to reduce muscle noise, following the approach of Thakor *et al.* (1990) [6]. Such filtering is customary in Automatic External Defibrillators (AED), with 1-30 Hz 'monitor-type' ECG bandwidth, in contrast with the 'diagnostic ECG (0.05-120 Hz). Thus the standard requirement for <5s amplifier recovery after defibrillation pulse was met and a tremor and power-line interference free signal was obtained.

2.2. ECG peak frequency

The ECG peak frequency was obtained by means of Fast Fourier Transform (FFT). Amplitude spectra were computed for consecutive 10s intervals. The spectral maximum was measured and taken as peak frequency.

2.3. Periodicity estimation

The VF signal periodicity was estimated by means of the parameter "leakage", proposed by Quo and Dillman [7]. It is equivalent to the output of a narrow bandstop filter centered on the mean signal frequency. The method relies on the fact that the VF signal is approximating a sinusoidal waveform. Thus the mean signal period was calculated by the following equation:

$$T = 2\pi \frac{\sum_{i=1}^{m} |V_i|}{\sum_{i=1}^{m} |V_i - V_{i-1}|} ,$$

where T is the number of data points in one mean period, V_i is the data sample and m is the number of samples in one analyzed data segment (10s).

The narrow bandstop filter was implemented by adding the data with a copy of the same data, shifted by a half period, which results in cancellation of periodic signals.

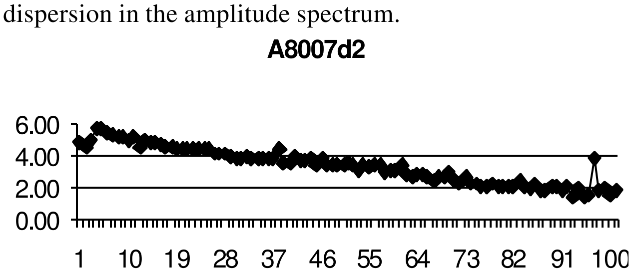
$$leakage = \frac{\sum_{i=1}^{m} \left| V_i + V_{i-T/2} \right|}{\sum_{i=1}^{m} |V_i| + \left| V_{i-T/2} \right|}$$

3. Results

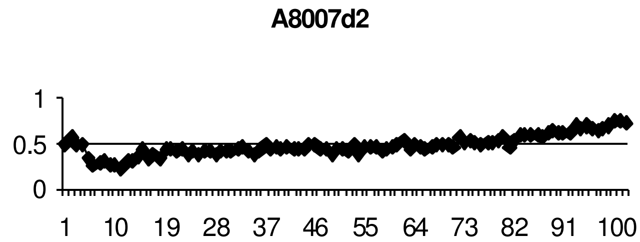
The ventricular fibrillation signal peak frequency decreased with elapsed time in N_1=21 of the total of 34 processed signals (62%). It fluctuated over a relatively constant value in the remaining N_2=13 cases (38%). The leakage parameter increased with time in N_3=15 of the assessed cases (44%), decreased in N_4=2 (6%) and fluctuated over a relatively constant value in the remaining N_5=17 (50%).

We estimated the dependences between the changes of both assessed parameters. The leakage increased in 57% of N_1, fluctuated over a relatively constant value in 33% of N_1 and decreased in 10% of N_1. In 77% of N_2, the leakage also fluctuated, and increased in the remaining 23% of N_2.

Figure 1 shows an example of the prevailing cases (35% of all), where decreasing VF frequency and increasing leakage corresponded to increasing frequency dispersion in the amplitude spectrum.



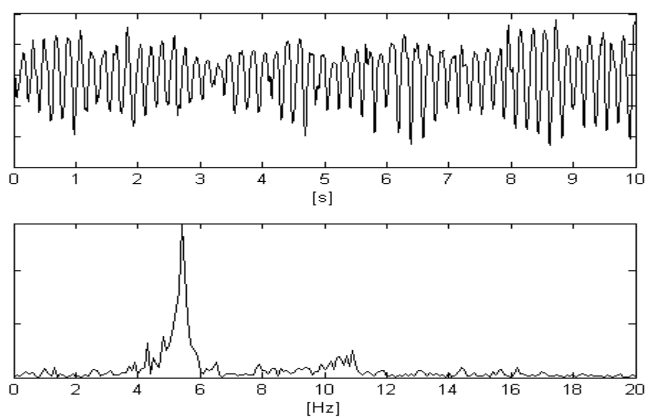
a



b

Figure 1.a) VF peak frequency in Hz versus consecutive number of 10s intervals;
b) leakage versus consecutive number of 10s intervals.

To demonstrate the relative similarity of the assessment by leakage parameter and by spectrum frequency dispersion, two 10s VF signal segments and their corresponding spectra are shown in Figure 2 a) and b). They are taken from the beginning and end of the same VF signal record, whose analysis was given in Figure 1.



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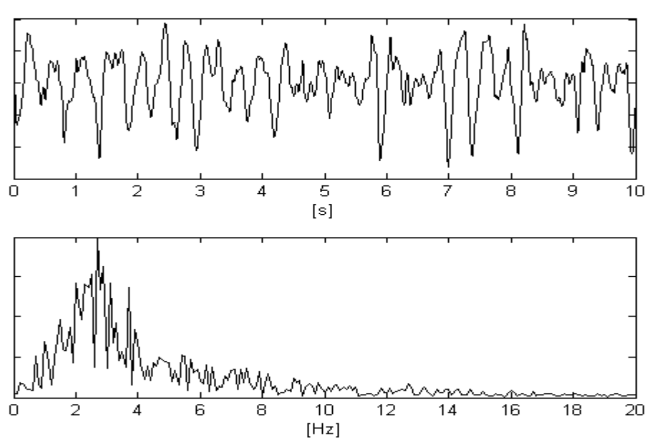

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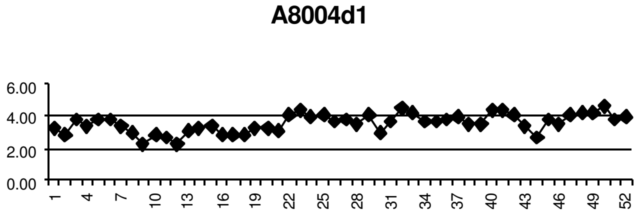
Figure 2. a) 10s VF signal segment from the beginning of the AHA A8007d2 VF record and its spectrum; b) 10s VF signal segment from the end of the same record and its spectrum.

The wider spectrum at the end of the VF record corresponds to higher leakage parameter value (higher number of frequency components) and to decreased signal periodicity.

Figure 3 shows an example of the second type of results (30% of all cases), where fluctuating VF frequency and leakage can be observed.



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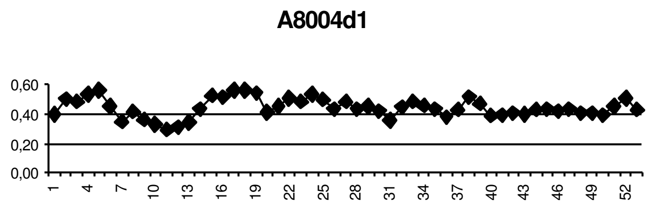
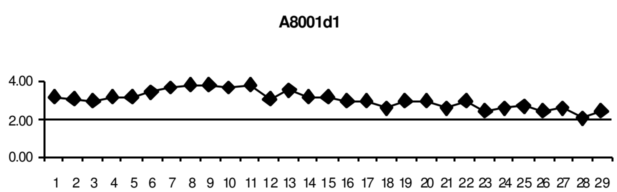


b

Figure 3.a) VF peak frequency in Hz versus consecutive number of 10s intervals; b) leakage versus the consecutive number 10s intervals.

Figure 4 shows an example of the third type of results (20% of all cases), where decreasing VF frequency and fluctuating leakage can be observed.



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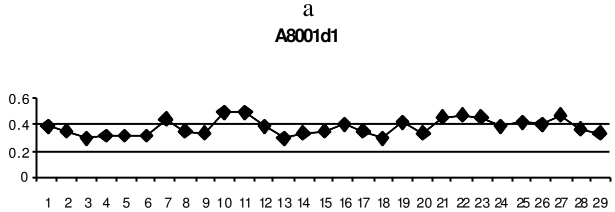

b

Figure 4.a) VF peak frequency in Hz versus consecutive number of 10s intervals; b) leakage versus consecutive number of 10s intervals.

The spectrum widths for the signals of Figure 3 and 4 are not shown because they vary depending on the specific time interval (the leakage parameter is fluctuating without tendency of increase or decrease) and are not indicative for the development of the VF signal.

4. Discussion and conclusions

Our results differ from those of Dzwoncyk et al. [3] and Martin et al. [8, 9]. They found a peak in the time-frequency relation of the analyzed VF signals. Dzwoncyk et al. reported that a maximum occurs in the median frequency at about 3.5 min from the beginning of VF. Martin et al. [8, 9] observed a maximum in the peak power frequency at a point somewhere less than 1 min. In both works signals with induced VF in animals (pigs and dogs) have been used. This could be the reason for the difference in the obtained results.

The tendency of the fibrillation frequency to decrease in time was moderately prevailing (62% of the cases), complemented partly (in 57%) by increased fluctuations reflected by the "leakage". In about 30% of the cases the signal peak frequency was relatively constant, but with fluctuating leakage parameter. Therefore, optimal timing for potentially efficacious defibrillation shock might be looked for only by methods for short-time (e.g. less than a few seconds) detection of the type of rhythm organization.

References

[1] Yakaitis RW, Ewy GA, Otto CW et al. Influence of time and theraphy on ventricular fibrillation in dogs. Crit. Care Med.1980; 8:157-163.

[2] Small M, Yu D, Harrison RG. Variation in the dominant period during ventricular fibrillation. IEEE Trans. on Biomed Eng. 2001; 48:1056-1061.

[3] Dzwonczyk R, Brown CG, Werman HA. The median frequency of the ECG during ventricular fibrillation: Its use in an algorithm for estimating the duration of cardiac arrest. IEEE Trans. on Biomed. Eng. 1990; 37:640-644.

[4] Brown CG, Griffith RF, Ligten PV, Hoekstra J, Nejman G, Mitchell L, Dzwonczyk R. Median frequency – A new parameter for predicting defibrillation success rate. Ann. Emerg. Med. 1991; 20:787-789.

[5] Eftestol T, Aase SO, Husoy JH. Spectral characterization of ECG in out-of-hospital cardiac arrest patients. Computers in Cardiology. 1999; 26:707-710.

[6] Thakor NV, Zhu YS, Pan KY. Ventricular tachycardia and fibrillation detection by a sequential hypothesis testing algorithm. IEEE Trans. Biomed. Eng 1990; 37:837-843

[7] Kuo S, Dillman R Computer detection of ventricular fibrillation. Computers in Cardiology 1978. Long Beach, California: IEEE Computer Society Press, 1978:347-349.

[8] Martin G, Gimeno JV, GuillenI, Cosin J. Effects of calcium antagonists on time course of ECG power spectrum during ventricular fibrillation. Computers in Cardiology 1983:213-216.

[9] Martin G, Cosin J, Such M, Hernandez A, Llamas P. Relation between power spectrum time course during ventricular fibrillation and electromechanical dissociation. Effects of coronary perfusion and nifedipine. European Heart J. 1986; 7:560-569.

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