Evaluation of T-wave Morphology Dispersion in High-Resolution ECG for Risk Stratification of Sudden Cardiac Death

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Abstract

The aim of study was to evaluate the prognostic value of T-wave morphology dispersion (TMD) in high resolution ECG for sudden cardiac death risk assessment.

The high-resolution ECG signals were recorded at rest in a electrically shielded room and averaged in time using cross-correlation method. The singular value decomposition was applied to HR ECG signals. Evaluated parameters were defined as the mean angle of all pairs of ECG leads reconstruction base vectors: for whole T wave segment (TMD), T-wave ascending slope (TMDpre), and T-wave descending slope (TMDpost). Sensitivity and specificity of T-wave morphology dispersion descriptors in detection of myocardial infarction patients at risk of ventricular tachycardia (VT) were tested on two groups: 30 pts. with documented VT and 13 pts. without VT.

Results of the study show significant differences between VT pts and non VT pts groups for all evaluated parameters. The highest sensitivity and specificity showed TMD parameter which could be sensitive marker of the risk of the sudden cardiac death. The presented results suggest that repolarization dispersion indicators may be used in qualification process to implantable cardioverter-defibrillator therapy.

1. Introduction

Cardiovascular diseases are characterized by the highest mortality rate among all lifestyle diseases. In European countries, heart disease causes 40% of deaths before the age of 74 [1].

New methods of early detection of cardio-vascular system dysfunction are intensively searched. In recent years, a number of electrocardiographic indicators of the cardiac repolarization abnormalities were proposed [2-10]. One of them is the T-wave morphology dispersion (TMD) parameter introduced by Acar et al [4]. This indicator is a measure of the spatial variability of T-wave morphology in standard 12-lead ECG.

The aim of the study was to examine the diagnostic value of the T-wave morphology inter lead dispersion parameters, calculated from high-resolution ECG recordings, in the detection of patients at risk of ventricular tachycardia.

2. Materials and methods

2.1. Study groups

The study was carried out in a group of 43 post-infarction men (average age 52.0 ± 13.4 years). The mean values of the T-wave morphology dispersion parameters (TMD, TMDpost, and TMDpre) were calculated and compared for the two groups of subjects: a group of 30 patients with documented ventricular tachycardia episodes, and 13 patients with no prior episodes of arrhythmia.

2.2. Measurements and signal preprocessing

The ECG signals were recorded in a shielded room using a 64-channel high-resolution ECG system. In order to increase the signal-to-noise ratio the cardiac beats were averaged in time using a cross-correlation method [11]. Only selected cardiac cycles with the correlation coefficient greater than 0.98 were averaged. The number of averaged heart beats (100 to 300 beats) depended on the level of noise observed in the ECG signal. Averaging procedure reduced the noise in the recorded ECG signals to a level below 1 microvolt. The eight independent leads (I, II, V1, V_2, V_3, V_4, V_5, V_6) of standard 12-lead ECG were used for further computations.

2.3 Calculation of cardiac repolarization dispersion descriptors

In the first step decomposition of eight standard ECG leads (I, II, V1, V2, V3, V4, V5, V6) on singular values (singular value decomposition – SVD) was performed [12].

$$M = U\Sigma V^T, \qquad (1)$$

where: M(*mxn*) – data matrix, U(*mxm*) – orthonormal

basis for the columns of the matrix M, V(*nxn*) – orthonormal basis for the rows of the matrix M, Σ – diagonal matrix of singular values of M, m – number of analyzed ECG leads (m=8), n – number of samples in averaged ECG signal.

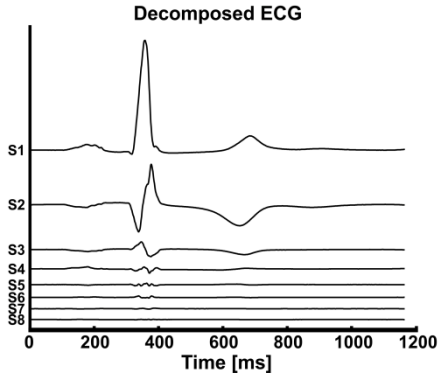

Figure 1. Dominant shapes of ECG signal ranked according to the information content (the result of the SVD procedure).

As a result of projection of data matrix M onto matrix U the eight independent components of ECG signal are obtained (eight orthogonal signals - Sn ,n∈ <1,8>) ranked in descending order of importance (Fig. 1). The first three components (S_1, S_2 and S_3) contained the highest amount of information (99% energy of 12-lead ECG [13]) are used in further calculations.

The procedure of QRS complex and T-wave fiducial points detection was based on an analysis of the S_1, S_2 and S_3 signals determined by the first three columns of the matrix U (u_1,u_2,u_3) ($\tilde{U}$) and the vector norm from these signals:

$$S_{3D}(t_i)=[s_1(t_i)\ s_2(t_i)\ s_3(t_i)]^T, \quad (2)$$

$$E_{3D}(t_i)=\left\|S_{3D}(t_i)\right\|_2. \quad (3)$$

This algorithm is described in more detail in Acar et al. [4].

In the next steps decomposed signal is normalized to 1, and the segments of signals S_1, S_2 and S_3 representing the T-wave are selected ($S_T(3,n)$). The ECG signal of T-wave for each lead is once again reconstructed for noise reduction and once more decomposed using SVD.

$$\tilde{M}_T=\tilde{U}S_T \quad (4)$$

$$\Sigma_T=U_T^T\tilde{M}_T V_T \quad (5)$$

The first two columns of the matrix U_T with largest ECG energy ($\tilde{U}_T$ (8x2)) are selected. Each of the rows of the matrix $\tilde{U}_T$ are the reconstruction vectors for a given standard ECG lead.

$$\tilde{U}_T=[\tilde{u}_{T1}\tilde{u}_{T2}]=[z_I z_{II}...z_{V6}]^T \quad (6)$$

ECG energy along two orthogonal dimensions of decomposition spaces $\tilde{u}_{T1}$ and $\tilde{u}_{T2}$ is proportional to the corresponding singular values σ_{T1} and σ_{T2}. Decomposition space is rescaled in order to focus on the changes in ECG morphology than on differences in signal energy.

$$W_T^T=\tilde{U}_T\tilde{\Sigma}_T=[w_I w_{II} w_{V1} w_{V2} w_{V3} w_{V4} w_{V5} w_{V6}]^T \quad (7)$$

Subsequent w_i vectors represent the reconstruction coefficients of the T wave in the *i*-th ECG lead. The angles between individual vectors w_i are calculated.

$$\phi_{ij}=\angle(w_i,w_j), i,j\in\{I,II,V1,V2,V3,V4,V5,V6\}, i\neq j \quad (8)$$

The smaller the angle ϕ_{ij} the more similar are the shapes of T waves in the i[th] and j[th] ECG lead (Fig. 2).

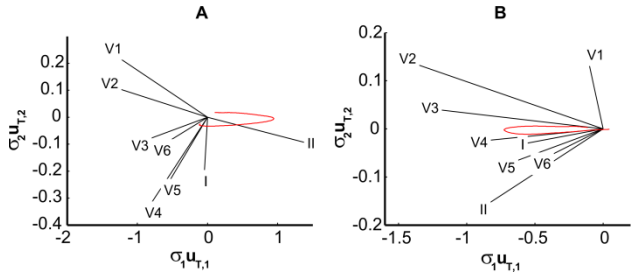

Figure 2. T-wave loops and reconstruction vectors (w_i) for each of the analyzed ECG lead: A - healthy volunteer, B – patient with documented ventricular tachycardia.

The TMD parameter describing T-wave morphology dispersion is defined as the average of all angles ϕ_{ij} excluding lead V_1:

$$TMD=\frac{1}{21}\sum_{i,j\in\Gamma}\phi_{ij}, \quad (9)$$

where Γ={I, II, V2, V3, V4, V5, V6}.

The TMD values express spatial variations of ECG signal morphology in whole T-wave segment. Small values of TMD parameter indicate that the reconstruction vectors of the analyzed leads are similar to each other, meaning that the T wave morphologies in different ECG leads are similar.

In the similar way two other parameters were defined [4] which present ECG morphology dispersion in the ascending part of the T wave (TMDpre) and in the descending part of the T wave (TMDpost).

3. Results

The mean values of the TMD, TMDpre and TMDpost and the corresponding standard deviations calculated in each group of studied patients are shown in Table 1.

Table 1. The mean values ± standard deviations of electrocardiographic parameters describing the variability of T-wave morphology in high-resolution ECG.

Parameter	Patients with VT	Patients without VT
TMD	76,14 ± 20,12	57,32 ± 23,06
TMDpre	79,20 ± 19,34	60,41 ± 26,52
TMDpost	73,33 ± 25,42	54,17 ± 26,39

Patients at risk of arrhythmia have been identified on the basis of the calculated parameter values and the designated threshold value (parameter value greater than or equal to the threshold). Values below the threshold determined the patients without the risk of sudden cardiac death.

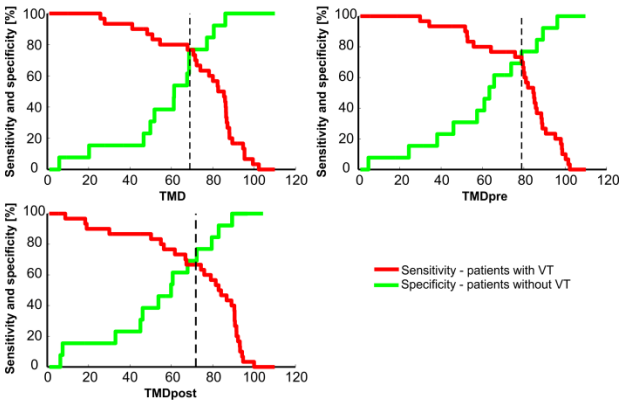

Figure 3. Result of the procedure determining an optimum threshold separating a group of patients with no history of ventricular tachycardia (without VT) and with documented episodes of arrhythmia (VT). Determined threshold values for calculated parameters were marked by dashed lines.

The threshold values of TMD, TMDpost, and TMDpre parameters, used to separate the two groups of patients: with a previous ventricular tachycardia (VT) and patients without VT, have been identified as the maximum value of the product of sensitivity and specificity values calculated in steps for the subsequent threshold (in steps equal to 0.001).

Table 2. Sensitivity and specificity values in the detection of patients with ventricular tachycardia.

Parameter	Sensitivity [%]	Specificity [%]
TMD	76,67	76,92
TMDpre	73,33	76,92
TMDpost	66,67	76,92

Figure 3 shows the result of this study for examined parameters, where the calculated threshold values are indicated by dashed lines.

4. Conclusions

Results of the study show significant differences in all evaluated parameters values between VT pts and non VT pts groups. The highest sensitivity and specificity showed TMD parameter which could be sensitive marker of the risk of sudden cardiac death. The presented results suggest that repolarization dispersion indicators could be used in qualification process to implantable cardioverter-defibrillator therapy. This preliminary findings needs to be confirmed by further analysis on larger group of patients.

Acknowledgements

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References

[1] Sans S, Kesteloot H, Kromhout D. The burden of cardiovascular diseases mortality in Europe. Task Force of the European Society of Cardiology on Cardiovascular Mortality and Morbidity Statistics in Europe. Eur Heart J 1997;18(12):1231-48.

[2] Janusek D, Pawlowski Z, Kania M, Kaczmarewicz S, Przybylski A, Maniewski R, editors. Vectorcardiographic representation of Concordant and Discordant T-wave Alternans. Proceedings of the Computers in Cardiology 2009; Park City, Utah, USA.

[3] Janusek D, Karczmarewicz S, Przybylski A, Pawlowski Z, Maniewski R. T-Wave Alternans Influence on Vectocardiographic Parameters. Computers in Cardiology 2008:327-8.

[4] Acar B, Yi G, Hnatkova K, Malik M. Spatial, temporal and wavefront direction characteristics of 12-lead T-wave morphology. Med Biol Eng Compu. 1999;37(5):574-84.

[5] Fereniec M, Stix G, Kania M, Mroczka T, Janusek D, Maniewski R. Risk assessment of ventricular arrhythmia using new parameters based on high resolution body surface potential mapping. Med Sci Moni. 2011;17(3):MT26-MT33.

[6] Kania M, Fereniec M, Janusek D, Zbiec A, Kepski R, Karpinski G, et al. Optimal ECG lead system for arrhythmia assessment with use of TCRT parameter. Biocybernetics and Biomedical Engineerin. 2009;29(2):75-82.

[7] Kania M, Fereniec M, Zbieć A, Kępski R, Karpiński G, Maniewski R. Evaluation of the QRS-T angle using the high resolution 64-lead electrocardiography. Anatol J Cardio. 2007(7 Suppl 1):120-2.

[8] Zabel M, Portnoy S, Franz MR. Electrocardiographic indexes of dispersion of ventricular repolarization: an

isolated heart validation study. J Am Coll Cardiol 1995;25(3):746-52.
[9] Rosenbaum D, Jackson L, Smith J, al e. Electrical alternans and vulnerability to ventricular arrhythmias. N Engl J Med 1994;330:235-41.
[10] Korhonen P, Husa T, Konttila T, Tierala I, Makijarvi M, Vaananen H, et al. Complex T-wave morphology in body surface potential mapping in prediction of arrhythmic events in patients with acute myocardial infarction and cardiac dysfunction. Europace 2009;11(4):514-20.
[11] Gomes J. Signal averaged electrocardiography: concepts, methods and applications: Springer; 1993.
[12] Golub GH, Van Loan CF. Matrix computations: Johns Hopkins Univ Pr; 1996.
[13] Acar B, Koymen H. SVD-based on-line exercise ECG signal orthogonalization. IEEE Trans 1999;BME-46:311-21.

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