Evaluation of the QRS-T angle using the high-resolution 64-lead electrocardiography

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ABSTRACT

Objective: The aim of the study was to evaluate the influence of the number of electrocardiogram (ECG) leads on the diagnostic value of TCRT (spatial QRS-T angle) parameter (12 standard ECG leads and 61 surface ECG leads were used). The TCRT parameter, which describes the spatial QRS-T angle, is a useful indicator of the risk of ventricular tachycardia (VT) and sudden cardiac death (SCD). It is usually calculated from standard 12 leads ECG.

Methods: The TCRT parameter was calculated from the three virtual orthogonal leads obtained by singular value decomposition of the averaged ECG signals. Sensitivity and specificity of TCRT parameter in identifying VT patients were tested on two groups of patients after myocardial infarction: 13 non - VT patients and 30 VT patients. Additionally 17 healthy volunteers were studied as a control group.

Results: Mean value (±SD) of TCRT parameter calculated for 61 leads was -0.80±0.27 for VT patients and 0.27±0.46 for non VT patients. For 12 standard leads TCRT mean value was -0.80±0.22 for VT patients and 0.27±0.49 for non VT patients. Sensitivity for VT patients was 87% (61 leads) and 83% (12 leads). Specificity in non-VT group was 100% for both lead sets.

Conclusions: Results of the study show distinct differences in the TCRT parameter values between VT patients and non VT patients for both lead sets. The sensitivities of the TCRT parameter obtained for 61 leads and for 12 standard leads were comparable.

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Key words: arrhythmia, vectorcardiography, risk factors

Introduction

Sudden cardiac death (SCD) is a major health problem and the most frequent cause of death among patients with cardiac diseases (1). The most common electrophysiological mechanism leading to SCD is an acceleration of cardiac rhythm called ventricular tachycardia (VT). It often evolves rapidly into ventricular fibrillation (VF) and may lead to SCD.

Well-known electrocardiographic prognostic parameters of cardiac morbidity and mortality are: the elevation or depression of ST segment (2), QT interval (3), QT dispersion (QTd) (4), T wave alternans (TWA) (5) as well as occurrence of late ventricular potentials (LP) (6).

Beside these clinically recognizable parameters, there are other proposals for measuring the heterogeneity of ventricular repolarization. Some of them, as for example ventricular gradient, were not used for years, because of a long computational time. Rapid progress in computers technology allows nowadays practical application of advanced analytical methods.

The theory of the ventricular gradient (7) is a base for the concept of the TCRT (spatial QRS-T angle) parameter, which is one of the most important risk factors of VT. This parameter was defined in 1999 by Acar et al. (8) as a cosine of the spatial angle between R and T wave of three orthogonal virtual vectors obtained by singular value decomposition (SVD). It is a measure of differences between direction of depolarization and direction of repolarization waveforms. The TCRT parameter is usually calculated from 12 standard electrocardiogram (ECG) leads. It seems that increase of numbers of ECG leads may improve sensitivity and specificity of this parameter in identifying patients threatened by VT. The aim of the study was to evaluate the influence of the ECG leads number on the diagnostic value of the TCRT parameter. Examination was performed on two sets of ECG signals (12 standard ECG leads and 61 lead set) obtained from the same patients group.

Methods

From 64 averaged ECG signals two subsets of data were selected. The first one consisted of eight standards ECG leads (I, II, V_1, V_2, V_3, V_4, V_5, V_6) and the second of 61 lead set.

Data analysis was based on three virtual orthogonal leads obtained by SVD of the averaged ECG signals (12). The SVD of a matrix M (mxn), in which m is the number of analyzed ECG channels, n is the number of samples in each channel (m>n) is given by the formula:

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

where U (mxm) and V (nxn) are square, orthogonal matrices and Σ is a diagonal matrix *mxn* of singular values ($\sigma_{ij}=0$ if $i \neq j$ and $\sigma_{11} \geq \sigma_{22} \geq \cdots \geq 0$). The matrices U and V are normalized, orthonormal ($U^TU=V^TV=I$, $U^{-1}=U^T$, $V^{-1}=V^T$) i.e. the columns form a basis. The first column of both U and V matrices includes k the most important components, so matrix M can be approximated as:

$$M_k \sim U_k \Sigma_k V_k T \text{ (where } k>=1) \quad (2)$$

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Acar and Koymen (13) have shown that 99% of the ECG energy can be represented in three-dimensional minimal subspace determined by three first columns of U (u1,u2,u3). Algorithm applied to detection of ECG characteristic points (onsets and offsets of both depolarization and repolarization waves) was based on analysis of three virtual, orthogonal leads (S1, S2 and S3) obtained as a result of projection of matrix with data onto matrix U. This procedure is described in detail in Acar et al. work (8).

The TCRT parameter is defined as an average of cosines of the angles between vectors formed loop of R wave in a subspace U and T wave vector (Fig. 1). The angle between these vectors determines difference in directions of spread of depolarization and repolarization waves.

Signal preprocessing

The ECG signals were recorded in the electrically shielded room using the high-resolution 64-lead ECG measurement system (3 limb leads and 61 leads set were used). Leads location corresponds to the University of Amsterdam lead system based on two 32 leads subsets selected by Lux (9-10) from 192 ECG leads by sequence selection algorithm (9). Measuring system consists of 64 low noise amplifiers with 16-bit A/D converters (BIOSEMI, the Netherlands). Signals were sampled with frequency of 4096 Hz and then transferred to the computer via an optical fiber. The data acquisition system was controlled by the LabView measurement software. To improve the signal-to-noise ratio the cross-correlation averaging (11) and filtering methods were applied to 64 recorded ECG signals. The number of averaged heart beats was dependent on the noise level in each measured signal (average 100-300 beats).

Data analysis

Range of physiological (from 0° to 130°, TCRT <1, -0.64)) and pathological (from 130° to 180°, TCRT <-0.64, -1>) values of angles between directions of main T wave and R wave vectors were determined according to Kardys et al. (14).

Analysis was done on the group of 60 men in the age range from 24 to 74 years (mean age 52.0±13.4 years). Specificity and sensitivity of the TCRT parameter in identifying patients with VT were calculated In two groups of patients after myocardial infarction: 13 non - VT patients and 30 VT patients. Additionally the TCRT parameter was calculated for a control group of 17 healthy volunteers.

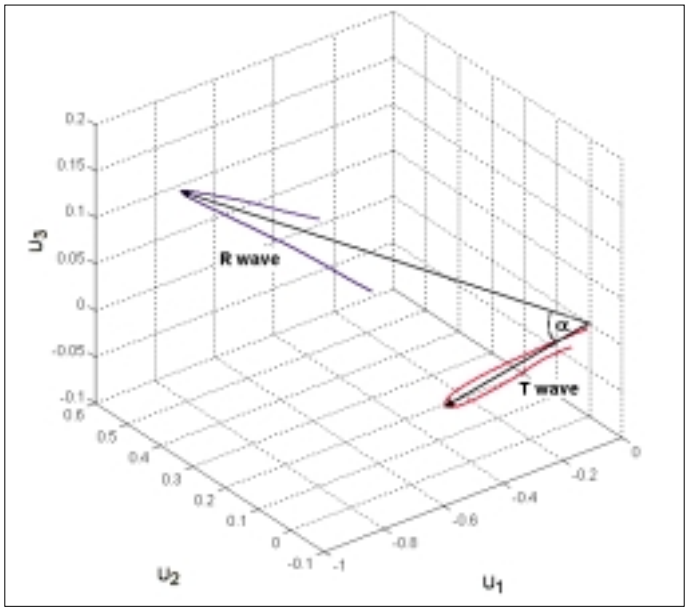

Figure 1. The spatial angle - between R and T wave vectors
Blue line- R wave loop, red line- T wave loop

Results

Mean value (±SD) of the TCRT parameter calculated for 61 leads was -0.80±0.27 (Median value (Me)=-0.88) for VT patients and 0.27±0.46 (Me=0.43) for non VT patients. For 12 standard leads TCRT mean value was -0.80±0.22 and median value was -0.88 for VT patients and 0.27±0.49 (Me=0.33) for non VT patients. Mean value of the TCRT parameter in control group for 61 surface leads was 0.22±0.40 (Me=0.30), however for 12 ECG leads was 0.11±0.52 (Me=0.25). Sensitivity of the TCRT parameter for detection of VT patients was 87% (61 leads) and 83% (12 leads). Specificity in non-VT group was 100% for both lead sets. Calculated values of specificity in control group for 61 and 12 ECG leads subsets were adequately 100% and 88%.

Discussion

In the obtained results, the distinct differences in the TCRT parameter values were observed between group of patients with VT and group of patients without VT for both lead sets. The sensitivity of the TCRT parameter in identifying VT patients was relatively higher and insignificantly better for 61 leads set in comparison with 12 standard ECG lead set. The results of the analysis show also significant increase of specificity of the TCRT parameter in control group in case of the 61 leads set in comparison to 12 standard lead set.

Conclusions

The results of the analysis confirmed the diagnostic value of the TCRT parameter in VT and SCD risk stratification. This parameter is less susceptible to noise level and problems of wave ends definition than other, more conventional ECG parameters, in particular the QT interval dispersion, where the problem of the T wave end definition cause controversies concerning the meaning of the QT dispersion parameter (15). Selection of 12 standard ECG leads for the TCRT parameter calculation seems to be a good solution. Application of set of 61 leads set insignificantly improved diagnostic value of the TCRT parameter. High prognostic value of TCRT parameter gives rise to statement, that it may be effective marker increasing efficiency of qualification process to implantable cardioverter-defibrillator therapy of patients after myocardial infarction.

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References

1. Priori SG, Aliot E, Blomstrom-Lundqvist C, Bossaert L, Breithardt G, Brugada P, et al. Task Force on Sudden Cardiac Death. European Society of Cardiology. Europace 2002; 4: 3-18.
2. Margonato A, Chierchia SL, Xuereb RG, Xuereb M, Fragasso G, Cappelletti A, et al. Specificity and sensitivity of exercise-induced ST segment elevation for detection of residual viability: comparison with fluorodeoxyglucose and positron emission tomography. J Am Coll Cardiol 1995; 25: 1032-8.

3. Jackman WM, Friday KJ, Anderson JL, Aliot EM, Clark MA, Lazzara R.The long QT syndromes: a critical review, new clinical observations and an unifying hypothesis. Prog Cardiovasc Dis 1988; 31: 115-72.
4. Zabel M, Portnoy S, Franz MR. Electrocardiographic indexes of dispersion of ventricular repolarization: an isolated heart validation study. J Am Coll Cardiol 1995; 25: 746-52.
5. Rosenbaum DS, Jackson LE, Smith JM, Garan H, Ruskin JN, Cohen RJ. Electrical alternans and vulnerability to ventricular arrhythmias. N Engl J Med 1994; 330: 235-41.
6. Maniewski R, editor. Nieinwazyjne metody badan serca i ukladu krazenia. Warsaw; IBIB PAN; 1996.
7. Geselowitz DB. The ventricular gradient revisited. IEEE Trans Biomed Eng 1983; 30: 76-7.
8. Acar B, Yi G, Hnatkova K, Malik M. Spatial, temporal and wavefront direction characteristics of 12-Lead T wave morphology. Med Biol Eng Comput 1999; 37: 574-84.
9. Lux RL, Smith CR, Wyatt RF, Abildskov JA. Limited lead selection for estimation of body surface potential maps in electrocardiography. IEEE Trans Biomed Eng 1978; 25: 270-5.
10. Lux RL, Burgess MJ, Wyatt RF, Evans AK, Vincent M, Abildskov JA. Clinically practical lead systems for improved electrocardiography: comparison with precordial grids and conventional lead systems. Circulation 1979; 59: 356-63.
11. Gomes JA. Signal-Averaged Electrocardiography: Concepts, Methods and Applications. Dordrecht; Kluwer Academic Publications; 1993.
12. Golub GH, van Loan CF. Matrix computations. 3rd ed. Baltimore and London: The Johns Hopkins University Press; 1996.
13. Acar B, Koymen H. SVD-based on-line exercise ECG signal orthogonalization. IEEE Trans 1999; 46: 311-21.
14. Kardys I, Kors JA, van der Meer IM, Hofman A, van der Kuip DA, Witteman JC. Spatial QRS-T angle predicts cardiac death in a general population. Eur Heart J 2003; 24: 1357-64.
15. Kors JA, van Hercen G. Measurement error as a source of QT dispersion: a computerized analysis. Heart 1998; 80: 453-8.