Study of T-wave Spectral Variance During Acute Myocardial Ischemia

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Abstract

Several studies have shown that beat-to-beat variability of ventricular repolarization morphology, which can be measured by T-wave spectral variance (TSV) index based on the 2D-FFT, is asociated with an increased risk for developing ventricular arrhythmias. In the present study we tested TSV index during percutaneous coronary intervention (PCI) procedure in the orthogonal X, Y and Z leads for both non-filtered T-waves (T_N) and filtered T-waves (T_F, which was obtained by reducing the ST-segment modification due to acute ischemia). Also, we analyzed the intraindividual and interindividual variations of TSV index, in order to determine reliable limits of significant repolarization variability due to an ischemic cardiac process. The study group consisted of 62 patients, in which two ECG control and one ECG recording during PCI-procedure were obtained. Results indicate that TSV index showed significant differences during PCI-procedure respect to control situation in all ECG leads for both T_N ($p < 10^{-8}$) and T_F ($p < 0.05$). Moreover, TSV index presented a high stability in each patient and a significant larger variability between patients. We conclude that TSV index offers a robust tool for evaluating beat-to-beat repolarization variability during acute ischemia.

1. Introduction

Ventricular repolarization dispersion (VRD) is a measure of inhomogeneous recovery of excitability during repolarization process, and it was demonstrated a relationship between increased VRD and severe ventricular arrhythmia [1]. Different techniques have been presented to analyze and quantify the temporal variability of ventricular repolarization [2]. Moreover, beat-to-beat measurement of the QT interval is based on the exact delineation of the T-wave end points, which frequently fail in automatic ECG analysis [3]. Also, the beat-to-beat changes were evaluated by using the T-wave spectral variance (TSV) index method, based on the two-dimensional Fourier transform (2D-FFT), which allow to detect dynamic changes in the repolarization pattern independently of the exact definition of the T-wave end. Steinbigler *et al.* showed that TSV reveal an increased VRD in patients prone to ventricular tachycardia and fibrillation after myocardial infarction, while the corrected QT interval showed no signficant differences [4]. Valverde *et al.* observed that TSV detected the presence of temporal repolarization variability in a model of chronic infarcted animals [5]. Other work showed that TSV was significantly higher in patients with idiopathic dilated cardiomyopathy prone to ventricular fibrillation respect to no ventricular fibrillation group [6]. The aims of this work were to analyze the TSV index method during acute myocardial ischemia in the orthogonal X, Y and Z leads and evaluate the intraindividual and interindividual variation of TSV index.

2. Materials and methods

2.1. Population

The study group consisted of 62 isquemic patients obtained from the Charleston Area Medical Center in West Virginia, receiving elective PCI-procedure in one of the mayor coronary arteries (STAFFIII study) [7]. The mean inflation duration was 4 m 28 s. Eight leads (V_1-V_6, I, II) were recorded using equipment by Siemens-Elena AB (Solna, Sweden) and digitized at sampling rate of 1 kHz and amplitude resolution of 0.6 μV. Synthesized orthogonal X, Y and Z leads were obtained by the Kors transform [8]. First, two control recordings were acquired continuously for five min in supine position prior to the PCI-procedure. Second, one continuous ECG was recorded during PCI-procedure. The occlusion sites of the PCI-procedures were: left anterior descending (LAD) coronary artery in 22 patients, left circunflex (LCX) coronary artery in 13, and right coronary artery (RCA) in 27.

2.2. ECG preprocessing

Signal preprocessing was applied to the X, Y and Z leads records during control and PCI-procedure respectively. Both controls and PCI-procedure ECG records were filtered with a notch filter (Butterworth, 2nd order, 60 Hz)

to minimize the power-line interference. A cubic spline interpolation filter was used to attenuate ECG baseline drifts and respiratory artifacts, and QRS complexes and their endpoints were detected. Moreover, for each ECG lead (both controls and PCI-procedure), one QRS template was constructed by calculating the median of the total QRS complexes. After that, if the cross-correlation coefficient between QRS template and each QRS complex was greater than 98%, a new jitter-corrected QRS complex is obtained, otherwise the complex was rejected.

Taken 80 ms from fiducial jitter-corrected QRS endpoint, it was defined a T-wave window of 300 ms duration in order to construct an aligned *T-waves non-filtering* (T_N) matrix. On the other hand, we noted that the ST-segment changes during PCI-procedure affect the T-wave morphology and, consequently, the estimates of beat-to-beat variability of ventricular repolarization morphology measures in this study. To compensate this effect, a T-wave processing was applied. The median value corresponding to the *N* consecutive T-waves was computed as $T_{m_i} = median\{T_{i-\frac{N-1}{2}}, ..., T_{i+\frac{N-1}{2}}\}$, with *i* denoting beat index and $N = 5$ beats. Then $\widehat{T}_i = T_i - T_{m_i}$ and later we aligned all the $\widehat{T}_i$ waves constructing a *T-waves filtering* (T_F) matrix. Those patients which have shown at least one T-waves matrix with less than 64 beats were rejected.

2.3. T-wave spectral variance index

The TSV index was calculated according [4]. First, a 1D-FFT is used and the frequency content of each T-wave in the T-waves matrix was determined. The result is a one-dimensional power spectrum from each T-wave, in which the x-axis correspond to the frequency content in Hz and the amplitude (z-axis) correspond to the magnitude of the power spectrum expressed in μV^2. A second 1D-FFT is applied to the T-waves spectrum assembly in order to evaluate the periodic appearance of each frequency content (y-axis), expressed in cycles-per-beat (cpb). TSV index was calculated by dividing spectral energy with beat-to-beat variability greater than zero cpb by total spectral energy from 0 Hz to 50 Hz.

The beat-to-beat variations in ventricular repolarization was evaluated in two differentes ways: 1) The TSV index was applied over T_N matrix and, 2) The TSV index was applied over T_F matrix, with the objective of evaluating the results of the TSV index with and without the ST-segment changes effect during myocardial ischemia.

2.4. Statistical analyses

In order to determine the statistical significance of TSV between control situation and PCI-procedure, a non-parametric two-sided Mann-Whitney U test was used. When *p* value was < 0.05, differences were considered statistically significant. Also,

$$\overline{TSV}_k^C = \frac{1}{J}\sum_{j=1}^{J} TSV_k(j) \quad (1)$$

was obtained for control and similarly, $\overline{TSV}_k^P$, was calculated for PCI-procedure, for each patient, $j = 1, ..., J$ and for each lead, $k = 1, ..., K$.

To asses the intraindividual variability [9] of TSV index, the difference between TSV index of both control recordings, $c = 1, 2$, was calculated as

$$D_k(j) = TSV_{k,1}(j) - TSV_{k,2}(j) \quad (2)$$

for each patient, $j = 1, ..., J$, and for each lead, $k = 1, ..., K$. Then, a statistical Wilcoxon signed rank test was applied to the difference $D_k(j)$ for all patients and for each lead, with the aim to evaluate the next hypothesis:

- H_0: the intraindividual change ($\overline{D}_k$) is zero
- H_1: the intraindividual change ($\overline{D}_k$) is different to zero

where

$$\overline{D}_k = \frac{1}{J}\sum_{j=1}^{J} D_k(j) \quad (3)$$

To asses the interindividual variability [9] of TSV index, the mean value of both TSV control indexes, $c = 1, 2$, for each patient, $j = 1, ..., J$, and for each lead, $k = 1, ..., K$, was calculated as

$$\overline{TSV}_k(j) = \frac{1}{2}\left[TSV_{k,1}(j) + TSV_{k,2}(j)\right] \quad (4)$$

The SD of $\overline{TSV}_k(j)$ over the whole population was denoted by $\chi_k^{\overline{TSV}\updownarrow}$. Moreover, the SD of the two TSV control indexes for each patient and each lead was denoted as

$$\chi_k^{TSV\leftrightarrow}(j) = \frac{1}{\sqrt{2}}\left|TSV_{k,1}(j) - TSV_{k,2}(j)\right| \quad (5)$$

Also,

$$\overline{\chi}_k^{TSV\leftrightarrow} = \frac{1}{J}\sum_{j=1}^{J}\chi_k^{TSV\leftrightarrow}(j) \quad (6)$$

was calculated. A statistical Wilcoxon signed rank test was applied to compare the intraindividual variability $\chi_k^{TSV\leftrightarrow}(j)$ with the interindividual variability of the whole population $\chi_k^{\overline{TSV}\updownarrow}$.

3. Results

From a total of 62 patients subject to balloon inflation procedure in one main coronary artery, the $TSV_k(j)$ was calculated during control situation and PCI-procedure. It can be observed that the $\overline{TSV}_k^P$ compared against $\overline{TSV}_k^C$ was statistically significant for all the leads (Fig.1).

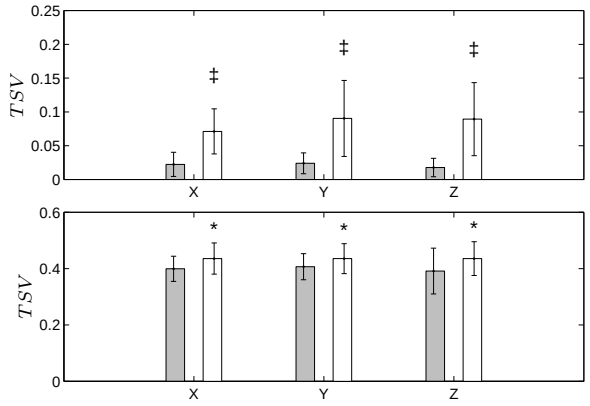

Figure 1. Bar graph showing $\overline{TSV}_k^C$ (gray bars) and $\overline{TSV}_k^P$ (white bars) indexes expressed as mean±SEM. Results from T_N (top panel) with ‡ $p < 10^{-6}$ and T_F (bottom panel) with *$p < 0.05$.

The low-intraindividual variability of TSV index variation was confirmed. In all leads, the hypothesis H_0, that indicates the intraindividual variability is zero, was accepted. See Fig. 2 (left panels).

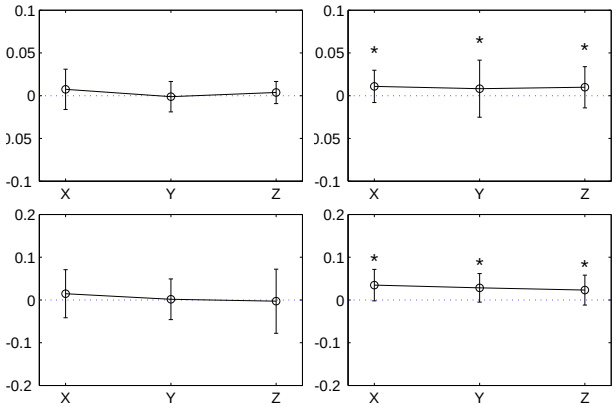

Figure 2. Intraindividual variability of TSV index (left panels) expresed as $\overline{D}_k$±SEM$\{D_k\}$ and interindividual variability of TSV index (right panels) expresed as $\overline{\chi}_k^{TSV\leftrightarrow}$±SEM$\{\chi_k^{\overline{TSV}\updownarrow}\}$ for each lead, *$p < 0.05$, being T_N (top panels) and T_F (bottom panels)

The interindividual variability of TSV index was calculated and the statistical test showed that the differences between the SD of each control, $\chi_k^{TSV\leftrightarrow}(j)$, and SD of the whole population, $\chi_k^{\overline{TSV}\updownarrow}$, were highly significant, p<0.05, being $\chi_k^{\overline{TSV}\updownarrow} > \overline{\chi}_k^{TSV\leftrightarrow}$ in all cases. The interindividual variability of how the SD of the TSV index at resting state during control vary within the whole population is showed in Fig.2 (right panels).

Figure 3 shows TSV index values measure in control and PCI-procedure for both T_N and T_F matrices of a patient from the STAFFIII database.

4. Discussion and conclusions

Modifications in repolarization have shown to play an important role in detect the probability to suffer ventricular arrhythmia. Patients and animals, with different classes of myocardial diseases, have presented beat-to-beat variability of repolarization morphology [4] [5] [6]. In this work we analyzed beat-to-beat repolarization variability in the orthogonal leads during acute ischemia and control. The results indicate that:

1) Intraindividual TSV index variability in different ECG control recordings showed that this index has high stability for each patient, thus giving reliable reference for the evaluation of beat-to-beat repolarization variability during acute ischemia. However, the interindividual TSV index variability is significantly larger, being necessary to propose a normalization criteria in order to have not a interindividual dependence.

2) The TSV index computed from T_N matrix showed significant differences ($p < 10^{-8}$) between control and PCI-procedure. We observed that the ST-segment level modification due to acute ischemia affects the T-wave morphology and in consequence the TSV index. Therefore, we have calculated the TSV index from T_F matrix, obtaining significant differences with $p < 0.05$ between control and PCI-procedure. This last statistical significance has less discriminative power than the obtained from T_N matrix, but this result could represent the intrinsical beat-to-beat repolarization variability .

Further clinical trials will be helpful to define whether the TSV index variation is useful to quantify cardiac risk in patients with different degrees of acute ischemia.

Acknowledgements

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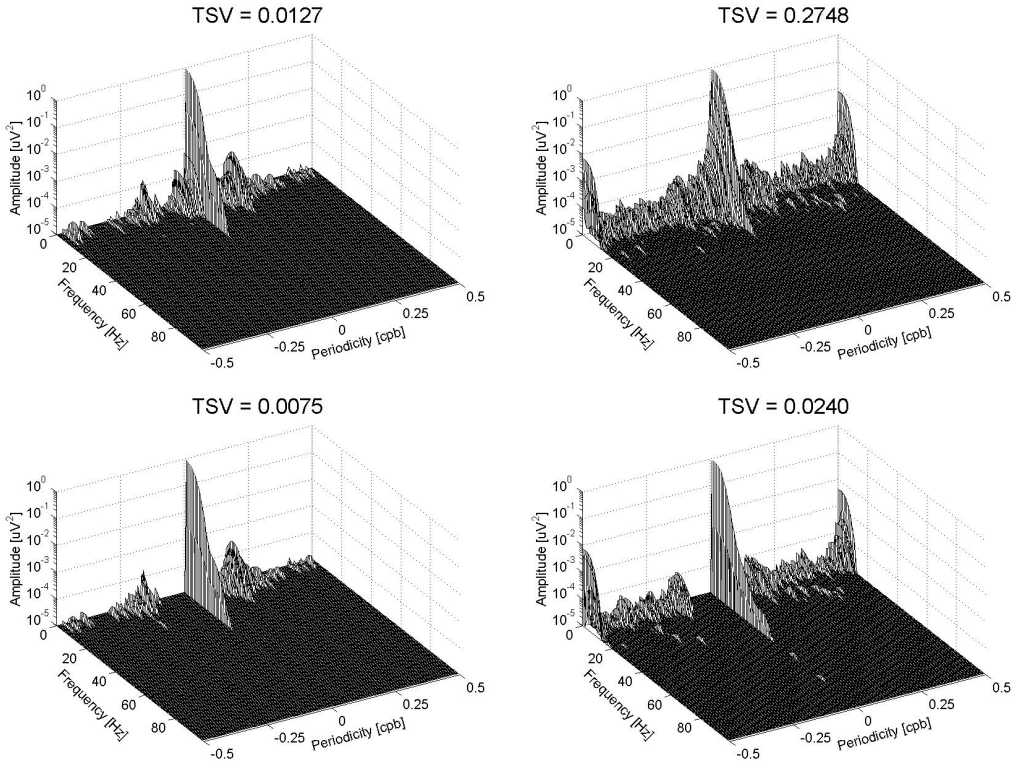

Figure 3. Example of power spectrum amplitude of the 2D-FFT represented in a normalized logarithmic scale showing control (left panels) and PCI-procedure (right panels) in Y lead, being T_N (top panels) and T_F (bottom panels)

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