# Vectorcardiographic Representation of Concordant and Discordant T-Wave Alternans

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## Abstract

*Vectorcardiographic representation of T-wave alternans (TWA) has been presented in new coordinate system created by means of singular value decomposition where the first axis was in T-loop direction and other axes were perpendicular. Projection of T-loop vector on the plane perpendicular to the first axis was analyzed. The study shows that in case of healthy people and those with detectable TWA, in whom no ventricular events were occurred, shape of consecutive T-loops does not change significantly from beat to beat. Detected TWA is supposed to be concordant, which is relatively benign. In electrocardiograms of patients who had ventricular tachycardia or ventricular fibrillation events, the shape of T-loops changes from beat to beat. It is supposed to be discordant TWA. It was showed that T-loop shape analysis can serve as noninvasive tool for differentiation between concordant TWA and discordant one what can help in better identification of patients at risk of sudden cardiac death.*

## 1. Introduction

Sudden cardiac death (SCD) is the leading cause of cardiovascular mortality in developed countries [1]. The efforts of many medical scientists and cardiologists are concentrated on the prediction and the prevention of SCD by finding the appropriate different diagnostic tools and therapies. The non-invasive assessment of the cardiac repolarization heterogeneity is of great clinical importance. It is generally accepted that the repolarization inhomogeneity facilitates the re-entry phenomena causing the development of life-threatening ventricular arrhythmias, e.g., ventricular tachycardia [2]. At present, there is no generally accepted non-invasive risk index of SCD. T-wave alternans (TWA) is a very promising marker of the risk of ventricular arrhythmia [3]. It is defined as beat to beat change in the amplitude of the ECG that repeats once every other heart beat and indicates the spatial heterogeneity of the ventricular repolarization. Currently, TWA measurements are performed using standard 12 lead ECG or orthogonal XYZ leads. In this study, vectorcardiographic representation of TWA was used [4]. Vectorcardiogram represents the spatial distribution of the electrical activity of the heart [5] and it allows for the evaluation of repolarization phase which, in case of the T-wave alternans, will change from beat to beat. TWA can be observed by analysis of propagation of the repolarization wave and their influence on the vectorcardiogram. Two different modes of the T-wave alternans were described in vitro study on animal model: concordant - relatively benign, and discordant – leading to ventricular fibrillation [6,7]. However, the mechanism of repolarization abnormalities causing concordant and discordant TWA is not fully explained and reliable methods of differentiation between both types of TWA in clinical conditions are not established yet.

## 2. Methods

Control group consisted of 10 healthy volunteers. Study group consisted of 18 patients with coronary artery disease and implanted cardioverter-defibrillator (ICD) in whom TWA was detected using FFT algorithm [8]. Eight of studied patients have ventricular fibrillation events after ICD implantation. They were defined as a group of patients with increased vulnerability to ventricular arrhythmia and sudden cardiac death. Because of high risk for ventricular fibrillation, T-wave alternans was classified as discordant. TWA detected in electrocardiograms of last 10 patients of the study group was classified as concordant because they did not have ventricular events in one year follow up after ICD implantation. In the study group, recordings were obtained during ventricular pacing (VVI) with the use of ICD electrodes at a pacing rate of 100 bpm. In the control group, vectorcardiographic signal acquisition was performed during sinus rhythm with a stable constant heart rate. Orthogonal XYZ lead configuration ECG system was used. Sampling frequency was 2 kHz and amplitude resolution was 22 bits.

Vectorcardiographic representation of electrocardiograms was analyzed. The new orthogonal coordinate system was created by means of singular value decomposition (SVD) where the first axis (u1) was in direction of maximal vector of the T-loop (direction of repolarization) and the second one was in the T-loop plane and it was perpendicular to the first axis. The system was created independently for every recording based on the first T-loop signal and it was fixed for the whole recording analysis. Main T-loop vector was selected as the vector which started at the beginning of the coordinate system, ended at the most remote point of the T-loop. The magnitude of main T-loop vector and its deviation from the first axis (u1) were analyzed. Beat to beat changes in the magnitude of this vector which describes changes in the length of T-loop as well as changes of angle between vector and the first axis of the new coordinate system were analyzed. It was used for description of T-loop location changes. Projection of the T-loop vector on the plane perpendicular to the first axis (u1) which includes the second (u2) and the third (u3) axes was analyzed.

## 3. Results

New orthogonal coordinate system was defined for vectorcardiographic TWA analysis. The first axis (u1) is in the direction of T-loop, the second axis (u2) lies on the plane of T-loop and it is perpendicular to the first axis. The third axis (u3) is perpendicular to both the first and the second axes. The diagram of T-loop in a new coordinate system and the location of the coordinate system in XYZ space are shown in Figure 1.

In the study group, two types of vectorcardiographic changes caused by T-wave alternans were found which were reported in the previous paper [4]. The first one shows T-loops similarity of a shape in every beat. T-wave alternans manifests as T-loop length changes from beat to beat. Probably, this type of TWA reflects concordant alternans. The second group consists of vectorcardiographic signals with T-loops which change their magnitude, location and shape from beat to beat. Differences in shape of T-loops are well reflected in the plane (u2 and u3 axes) perpendicular to the T-loop main vector (u1 axis direction). In Figure 2, 3 and 4, projections of the T-loop vector on the plane perpendicular to the T-loop are shown. Changes in location and magnitude have been already presented.

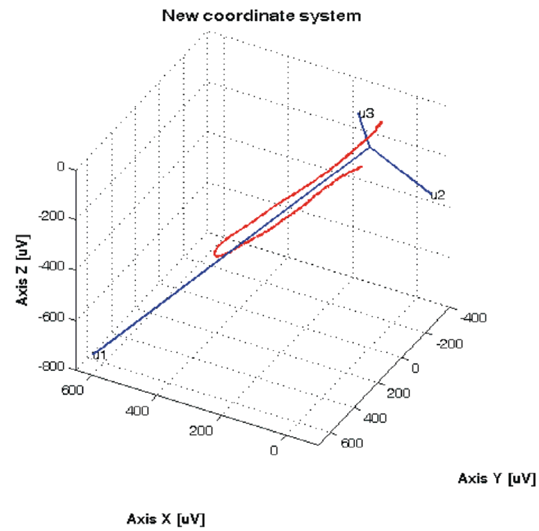


Fig. 1 T-loop in new coordinate system

In Figure 2, projection of T-loop recorded in healthy person is shown. T-loop signal from a patient with ICD who does not have ventricular events after implantation is shown in Figure 3. Because of drug therapy and lack of ICD intervention this patient can be considered as resistant to ventricular fibrillation and his TWA can be classified as concordant. In both above cases, the movement of vector projection is similar for every consecutive heart beat (similar projection diagram).

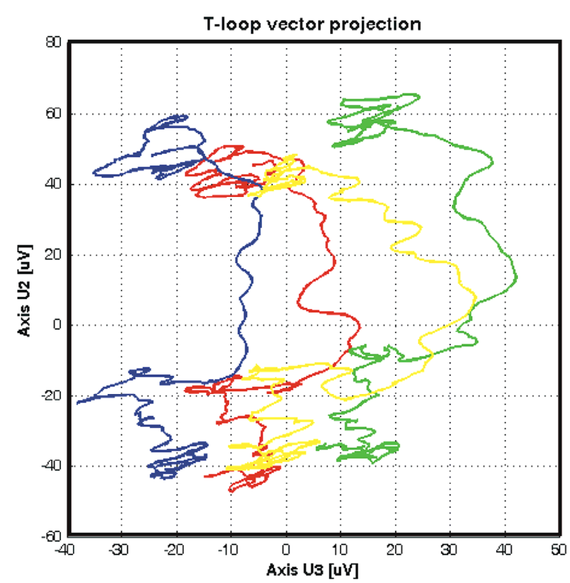


Fig. 2 T-loop vector projection on the plane perpendicular to the first axis obtained from healthy person.

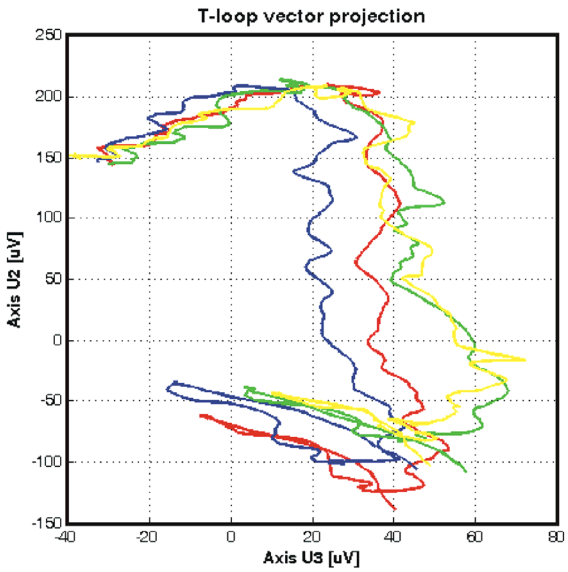


Fig. 3 T-loop vector projection on the plane perpendicular to the first axis obtained from the patient with ICD and TWA which are supposed to be concordant

A signal from the patient with ICD who suffered from ventricular fibrillation after ICD implantation is shown in Figure 4. That patient should be considered as one of high risk of the SCD. In this case, shape of T-loops projection is changing between even and odd heart beats and vector tracks multiple loops during a single heart cycle.

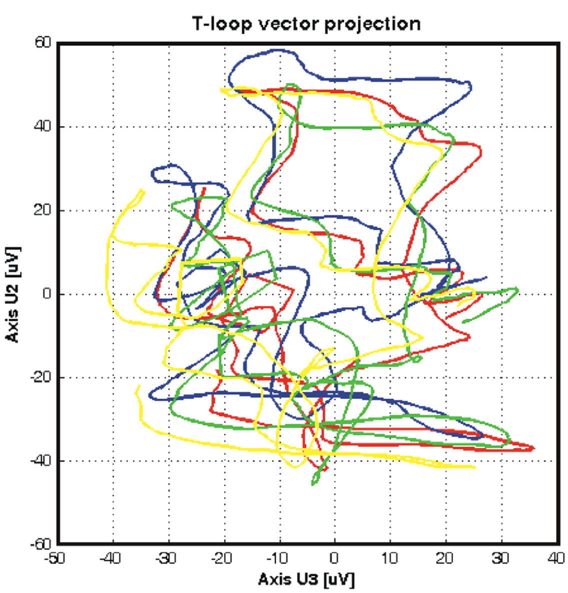


Fig. 4 T-loop vector projection on the plane perpendicular to the first axis obtained from patient with ICD and TWA which are supposed to be discordant.

## 4. Discussion and conclusions

Vectorcardiographic T-loops in signals obtained from healthy people are usually similar for particular recordings but they may change their shape between different persons.

In vectorcardiographic signals with detectable T-wave alternans, the significant changes in the length and the position of the T-wave loop vectors have been presented between odd and even heart beats. These results show that there are at least two mechanisms which influence on T-wave alternans signal observed in electrocardiograms. The relation between intensity of these two phenomena for various patients is different.

Methods of investigation of electric instability in a spatial course of VCG vector were proposed. By means of SVD, transform representation of dispersion in repolarization process was showed. Vectorcardiographic representation of signals recorded in patients with ICD and with low risk of ventricular fibrillation shows similar shape of the T-loop projection on the perpendicular plane in every other heart beat which could be an indicator of presence of concordant TWA. Usually, there are loops which correspond to increasing and decreasing part of the T wave in electrocardiogram. It shows heterogeneity of repolarization process.

In patients with ICD and at high risk of ventricular fibrillation, T-loop vector projection on perpendicular plane changes its shape from beat to beat. Probable source of such changes could be re-entrant waves. Changes of propagation direction in repolarization wavefront can contribute to arrhythmia generation. This type of TWA may reflect discordant alternans. In vectorcardiographic signals of people at risk, both concordant and discordant TWA can be found.

Proposed vectorcardiographic analysis in the plane perpendicular to the T-loop main vector allows for distinguishing between concordant and discordant T-wave alternans.

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