

A METHOD FOR ECG T-WAVE ALTERNANS DETECTION BASED ON SEGMENTED PHASE CURVE DISTANCE

Masaki Nozawa, Kazuo Yana^a, Ryota Seki^a, Kunihiro Yoshino^a and
Takuya Ono^b

^aDepartment of Applied Informatics, Hosei University, Tokyo, JAPAN

^bDepartment of Cardiology, Nippon Medical School, Tokyo JAPAN

Correspondence: Kazuo Yana, Department of Applied Informatics, Hosei University, Tokyo
Japan. E-mail: yana@hosei.ac.jp, phone +81-42-387-6188, fax +81-3-3368-8165

Abstract. This paper proposes a method of T-wave alternans (TWA) detection based on Holter ECG recordings. The T-wave loop composed of orthogonal signals underlying the original ECG record has been utilized for the alternans detection. In this study the loop is divided into four phases according to the T-wave time progression. Then for each phase, the beat to beat alternate changes are detected by the intensity of the periodogram of successive phase curve difference sequence. The method was applied to 30 subjects (10 normal, 20 patients with cardiac disease) to confirm its effectiveness for the TWA detection. The study revealed that the method may be useful to evaluate the risk of sudden cardiac death utilizing the standard Holter ECG recordings.

Keywords: T-wave alternans; Sudden Cardiac Death; ECG, Singular Value Decomposition

1. Introduction

The T-wave alternans (TWA) has been known as an index to evaluate the risk of sudden cardiac death (SCD) [Kaufman *et al.*, 2006] [Rosenbaum, 2008]. Conventional method of TWA detection requires controlled testing environment to impose cardiac loads to subjects on a testing bench [Rosenbaum *et al.*, 1994]. Authors have proposed a sensitive method enabling the TWA detection in less restrictive environment with Holter noisy recordings [Kaeriyama *et al.*, 2010]. The method utilizes the singular value decomposition (SVD) of three channel Holter ECG recordings. Here the detection of characteristic changes in T-wave loop constructed by the decomposed orthogonal signals is the major objective. Alternate changes in the loop vector lengths or angles have been proposed to be utilized for the detection. They are indices to capture the characteristics of whole T-wave morphology. It is known that different phase of T-wave morphology is affected depending on the type of cardiovascular diseases. Thus, this paper examines the beat to beat changes in different phase of T-wave loop morphology for more precise characterization of the T-wave alternans.

2. Material and Methods

Three channel Holter ECG recordings (*Spiderview: ELA Medical, Cedex France*) from fifteen normal subjects (NML) and thirty patients with clinical abnormality are analyzed. Fifteen patients (PLR) have low SCD risks with benign arrhythmia and/or hyper tension. Other fifteen patients (PHR) with high SCD risks have ischemic heart disease and cardiomyopathy with lethal arrhythmia or syncope. Data were digitized at the sampling rate of 200 Hz and processed off line. Data analysis consists of the following three steps.

2.1. Step1: Baseline correction

Spline smoothing technique is adopted for the baseline correction in order not to affect T-wave morphology. Slow baseline drift is estimated by spline smoothing technique applying it to the signal portion supposed to be electrically inactive, *i.e.* the period between the end of T-wave and shortly before the p-wave initiation. The period was empirically set at the interval between 60% and 80% of the RR times. Then the baseline drift signal is evenly resampled and subtracted from the original ECG data yielding the baseline corrected ECG signals.

2.2. Step 2: T-wave signal decomposition

Let's $x[n; k, m], n = 1, \dots, N; k = 1, \dots, K; m = 1, \dots, M$ be the original T-wave signals. T-waves are extracted as ECG signal fall in the period between 100 to 400(ms) after the R-peak time. Here, n, k and m respectively denote the sample data point number, ECG channel number and the beat number of the record. Underlying orthogonal signals:

$$s[n; k, m], n = 1, \dots, N; k = 1, \dots, K; m = 1, \dots, M$$

are obtained by the Singular Value Decomposition (SVD). SVD decomposes the original signal matrix X into the following form.

$$X = U\Sigma V^T = US.$$

Here the k -th row of the matrix X and S respectively denotes k -th original and underlying orthogonal signal. Singular values are diagonal part of the matrix Σ . Orthogonal signals are sorted by the magnitude of corresponding singular values. Then, T-wave loop is constructed by two dominant orthogonal signals. The loop is defined as a phase curve of two dominant orthogonal signals $s[n; k, m], k = 1, 2$ with n being the common parameter [Acer *et al.*, 1999]. Accumulated singular value exceeds 0.95 with two orthogonal signals.

2.3 Step 3: TWA detection per distinctive T-loop phase

To examine the difference in alternate changes at different T-wave phase, the T-wave loop is divided into four segments. The mid T-wave point n_{mid} is defined as the sample point which gives the maximum norm of the T-wave loop for each beat, *i.e.*:

$$\frac{1}{2} = \arg \max_n \left\{ \sqrt{\sum_k s^2[n, k, m]} \right\}.$$

Then phase 1-4 of the T-loop are defined as time intervals shown in the table 1 and Fig. 2

Table 1. Phase division of the T-loop

	Phase 1	Phase 2	Phase 3	Phase 4
Data Range	$N_1 = \left[1, \frac{n_{mid}}{2} \right)$	$N_1 = \left[\frac{n_{mid}}{2}, n_{mid} \right)$	$N_1 = \left[n_{mid}, \frac{3}{2}n_{mid} \right)$	$N_1 = \left[\frac{3}{2}n_{mid}, N \right)$

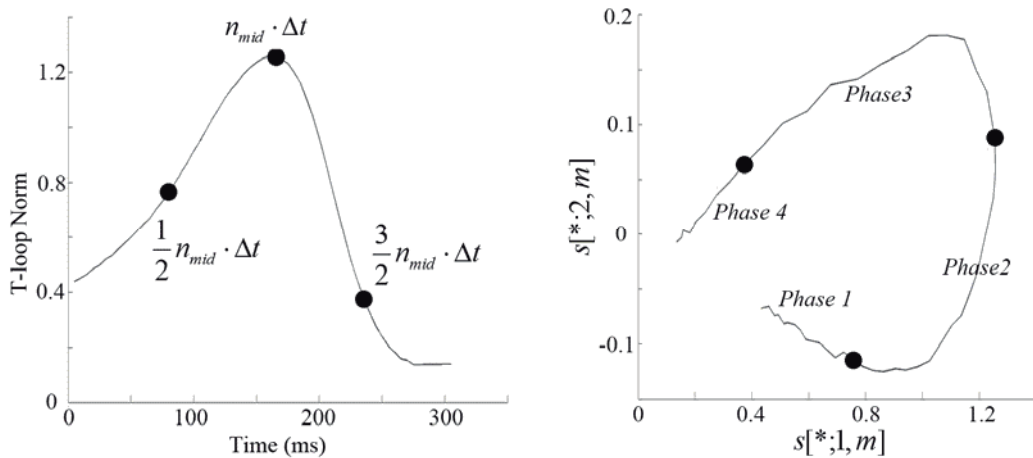


Figure 1. Phase division of the T-loop (Left: T-wave norm, Right: segmented T-wave loop)

Successive beat to beat phase curve distance (SPD) sequence:

$$d[m; p] = \sqrt{\sum_{n \in N_p} \frac{(S[n;1,m] - S[n;2,m])^2}{S[n;1,m]^2 + S[n;2,m]^2}}, m = 1, \dots, M$$

is then calculated for each phase p . Typical SPD sequences are shown in Fig. 2.

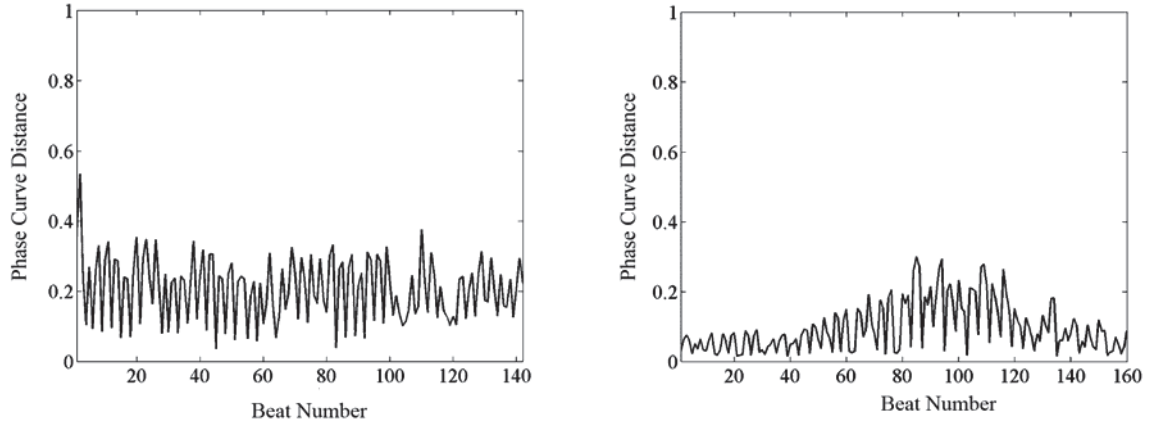


Figure 2. Typical example of the phase curve distance sequence for phase 2
(Left: a normal subject ; Right: a subject with high SCD risk)

TWA is detected by identifying the presence of beat to beat alternation in the SPD sequence. The magnitude of the periodogram at the Nyquist frequency is utilized for the detection.

3. Results

Fig. 3 shows a typical example of the periodogram of the SPD sequence for the phase 2 of normal subject and a patient with high SCD risk. Prominent intensity at the Nyquist frequency can be seen for the case of high risk patient.

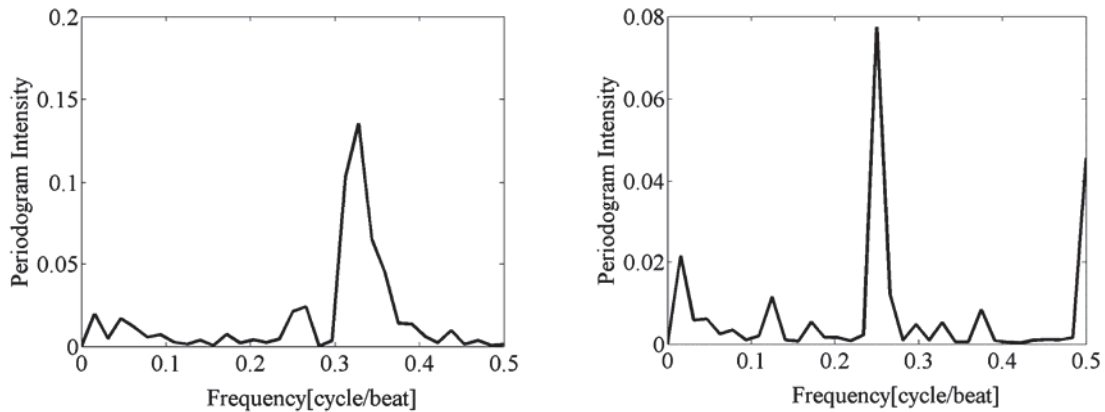


Figure 3. Typical example of periodogram of the phase curve distance sequence
(Left : a normal subject ; Right : a subject with high SCD risk)

Fig. 4 shows the distribution of periodogram intensity at the Nyquist frequency for each phase. Clear differences in the intensity among subject groups can be observed except for the phase 4.

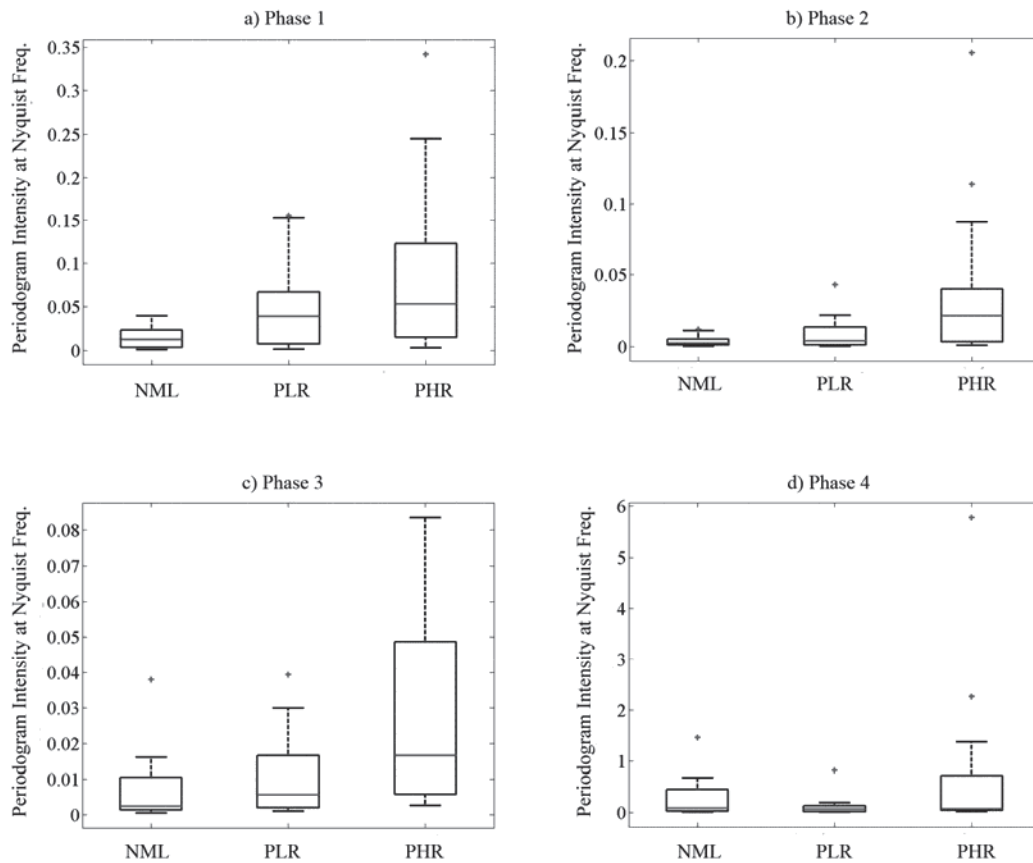


Figure 4. Distribution of Periodogram Intensity at the Nyquist Frequency for each phase of the T-wave loop
(NML: Normal Subjects, PLR: Patients of Low SCD Risk, PHR: Patients of High SCD Risk)

The results are summarized in Table 2. It is apparent that the higher the periodogram intensity the higher the SCD risk.

Table 2. Summary of Periodogram Intensities at the Nyquist Frequency

Subject	Phase 1	Phase 2	Phase 3	Phase 4
NML	0.0145±0.0129	0.0038±0.0039	0.0076±0.0104	0.2782±0.4213
PLR	0.0504±0.0530	0.0090±0.0123	0.0109±0.0121	0.1286±0.2165
PHR	0.0922±0.1036*	0.0397±0.0609**	0.0313±0.0291**	0.8156±1.6361

Figures with *, ** show they are statistically significant compared to normal subjects
(*: $p < 0.05$, **: $p < 0.01$).

4. Discussion and Conclusion

Periodogram of the SPD sequence often shows prominent peaks at 0.25-0.35 cycles/beat besides the target peak at Nyquist frequency. The origin of those peaks is the respiratory rhythm indicating the needs to improve the base line correction algorithm. Identification of inactive portion of the ECG activity is to be more accurate. Nevertheless, the presence of respiratory peak in the SPD sequence will not affect the result of TWA detection accuracy since the periodogram differentiate frequency component relevant to the presence of TWA.

The intensity of SPD spectrum at the Nyquist frequency is shown to be effective in TWA detection except for the phase 4. Phase specificity of the index to the degree of risk is not observed among phase 1,2 and 3. The specificity may be found by increasing the database sufficient to examine the differences among different types of heart failure or decease.

References

- Kaufman ES, Bloomfield DM, Steinman RC, Namerow PB, Costantini O, Cohen RJ. Indeterminate microvolt T-wave alternans tests predict high risk of death or sustained ventricular arrhythmias in patients with left ventricular dysfunction. *J. American College of Cardiology*, 48: 1399-1404, 2006.
- Rosenbaum DS. T-wave alternans in the sudden cardiac death in heart failure trial populatio. *Circulation*, 118: 2015-2018, 2008.
- Rosenbaum DS, Jackson LE, Smith JM, Garan H, Ruskin JN, Cohen RJ. Electrical alternans and vulnerability to ventricular arrhythmias. *N. Engl. J. Med.*, 330: 235-241, 1994.
- Kaeriyama K, Nozawa M, Shichiku H, Yana, K, Mizuta H. and Ono, T. T-wave Vector Alternans Detection based on Holter ECG Recordings. *International Journal of Bioelectromagnetism*, 12(4): 165-169, 2010.
- Acar B, Yi C, Hnatkova K, Malik M. Spatial, temporal and wave front direction characteristics of 12-lead T-wave morphology. *Med. Biol. Eng. & Comput.*, 37: 574-584, 1999