Principal Component Analysis for Detection and Assessment of T-Wave Alternans

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Abstract

T wave alternans (TWA) is an electrophisiologic phenomenon associated with a risk factor of sudden cardiac death. In the framework of Physionet/Cinc Challenge, a set of 100 ECG recordings were collected in order to test different algorithms for the detection and the quantification of TWA.

The ECG were processed for power line interference, electromyographic noise and baseline wander suppression. Two kind of algorithm were tested, considering the temporal domain: 1) the T wave amplitude computed in a combined lead, and 2) the Principal Component Analysis for quantifying the complexity index of the T waves. The detection of possible alternans was performed by a paired non parametric statistical test. Our study proved a high correlation between alternans of T amplitude and the alternans of T wave complexity index. The results of an algorithm combining the outcome of the two methods for the detection of TWA showed a score of 0.890, second best in the Challenge.

1. Introduction

T-wave alternans is a prognostic indicator of preceding episodes of Torsade de Pointes life-threatening arrhythmia [1], and is an electrophysiological phenomenon associated with a risk factor of sudden cardiac death. Linkage between TWA and susceptibility to malignant arrhythmias has been reported at above 75% of the controls ($p < .05$) [2].

TWA appears in the electrocardiogram as a consistent fluctuation in the repolarization morphology on every-other beat basis. The computerized ECG analysis led to the discovery, and routine clinical assessment, of invisible to the naked eye microvolt TWA [3-5]. TWA appears at a specific heart rate, generally in the range of 90 to 120 beats per minute, and can be achieved using bicycle or treadmill stress test. Both exercises have almost equal effect [6].

Heart rate alone appears to be the main factor of determining the onset of TWA during submaximal exercise stress tests [6].

Weber *et al.* [7] investigated the prevalence of TWA in healthy subjects. TWA was not observed in any individual at rest. Short transient intervals of TWA were observed during exercise in 10.4% of the healthy controls (30 ± 8 years). Sustained TWA was observed in 4.2%.

A variety of algorithms for detecting and quantifying TWA have been proposed, employing techniques as spectral analysis, complex demodulation, zero-crossings counting in a series of correlation coefficients, Karhunen-Loève transform, low-pass Capon filtering, Poincaré mapping, periodicity transforms, statistical tests, modified moving average, Laplacian likelihood ratio, etc.

A review by Martínez and Olmos [8] highlights the need for methodological systematization effort in characterization and comparison of the different methods.

A multilead approach to T-wave alternans detection combining PCA and the Laplacian likelihood ratio method is proposed by Monasterio and Martínez [9].

The aim of this study is to assess the detection and quantification of TWA, by the performance of two combined methods: Twave amplitude statistical analysis and PCA in the framework of PhysioNet/Computers in Cardiology 2008 Challenge [10].

2. Methods

A set of 100 ECG recordings were selected and collected in the framework of the Challenge [10] in order to test different algorithms for the detection and the quantification of TWA. These recordings consisted of 16 with 2 leads, 12 with 3 leads and the remaining 72 recordings with 12 leads.

2.1. Signal preprocessing

Moving averaging of samples in one period of power-line interference was performed. This filter is meant to eliminate the power-line interference. Its frequency response is having a first zero at interference frequency 50 Hz (60 Hz).

A smoothing procedure for EMG noise suppression is applied [11]. It uses the least-squares approximation method, applied for defining the weighting coefficients for each sample of the selected smoothing interval of 60 ms.

A high-pass recursive filter for drift suppression with a cutoff frequency of 0.64 Hz has been used [12].

QRS detection using combined adaptive thresholding was applied [13].

T wave onset and offset delineations were automatically performed [14], and the T amplitude was calculated, in a combined lead simulating the spatial vector [12] or another all-inclusive signal, rather than in the separate leads. The transform to the orthogonal leads (X,Y,Z) was performed in [12] using 'primary leads', i.e. the 8 potential differences referred to the electrode of the left leg F. These primary leads were obtained from the 12-lead ECG recordings, following the conversion formulae in the [15]:

$R_F = -II$; $L_F = -III$; $Ci_F = Vi - (II+III)/3$

The orthogonal leads were evaluated by:

$X=0.5*abs(C4_F-C1_F)$;

$Y=abs(R_F)$;

$Z=abs(R_F -C2_F)$;

The combined lead (CL), which is the spatial vector in this case, is calculated by:

$CL=0.5(X+Y+Z+0.25(abs(X-Y)+abs(X-Z)+abs(Y-Z)))$;

In cases of 3-leads ECG: X=Lead1; Y=Lead2; Z=Lead3.

In cases of 2-leads ECG: X=Lead1; Y=Lead2; Z=0.

2.2. TWA detection

The proposed approach takes into consideration three aspects of the TWA detection task: the parameter selection, the interval selection and the classification bock.

In selecting the more appropriate parameter for TWA classification, the multi-lead approach has been followed, in order to extract a single index from the entire ECG record. Two parameters were chosen, considering the temporal domain: 1) the amplitude and 2) the complexity index of T waves. In the first case, a combined lead was determined with all the leads at disposal (2, 3 or 12), simulating the spatial vector, in which T wave onset and offset delineations were performed, and the amplitudes were computed.

The second parameter for TWA discrimination considers the use of Principal Component Analysis (PCA) for quantifying the complexity index of the T waves. In particular the PCA has been applied to the intervals of T waves, and the ratio of 2nd/1st eigenvalues characterizes the complexity index.

In the interval selection two methods were applied: global and local (see Figure 1). In the global method, the entire ECG recording was processed, producing a unique time series, which feed the detection block. The local method considers a set of variable length windows of RR intervals, and performing the parameter extraction in each of them. In particular this method considers a window of 128 RR intervals, shifting it in the entire ECG recording.

The detection block performs first, the separation of the parameters from odd and even RR intervals, and then the two series was compared in order to discover the presence of significative differences. The statistical analysis which provides the significance of the differences between odd and even samples was performed by the non parametric paired-sampled Wilcoxon signed rank test.

In the case of Global methods, the statistical test produces a single binary index, which represents the presence or absence of TWA. In the case of Local methods, this process is repeated for every interval, producing a set of binary indices, and the number of intervals with positive indices is considered. In case it is higher/lower of a predetermined threshold, it signifies the presence/absence of TWA.

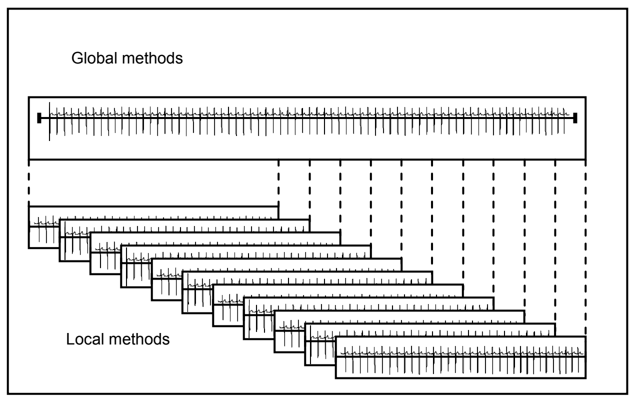

Fig.1. Methods for the interval selection for the detection of TWA: global (entire record) and local (a set of windows)

All the RR intervals were analyzed, independently by the presence of noise or artifact. In addition, the heart rate was not considered for the determination of the presence/absence of TWA.

3. Results

The Computers in Cardiology Challenge made available a score system in order to rank the various methods. The score takes values in the range -1, +1.

Five methods have been tested for the detection of TWA:

- GLB1: a global index considering the alternans of the T amplitude on the entire ECG recording
- GLB2: a global index considering the PCA index on the entire recording
- LOC1: a local index considering the alternans of the T amplitude in various windows of 128 RR intervals
- LOC2: a local index considering the alternans of the PCA index in the individual intervals
- COMB: an index combining the previous indices, and requiring essentially a positive test in both the global and the local in dices.

Table 1 reports a cross tabulation of the number of records with the presence of TWA with the 5 considered methods.

Table 2 reports the percentage of agreement in the detection results between all the combinations of two methods, while Table 3 reports the correlation coefficient between them.

Table 1. Number of TWA determined by the 5 methods: Comb (Combined), GLB1 (Global T amplitude), .GLB2 (Global PCA_T), LOC1 (Local T amplitude), and LOC2 (Local PCA_T).

	Comb	GLB1	GLB2	LOC1	LOC2
Comb	25				
GLB1	25	29			
GLB2	20	20	28		
LOC1	23	27	18	31	
LOC2	19	19	20	17	24

Table 2. Agreement between the 5 different methods of TWA detection: Comb (Combined), GLB1 (Global T amplitude), .GLB2 (Global PCA_T), LOC1 (Local T amplitude), and LOC2 (Local PCA_T).

	Comb	GLB1	GLB2	LOC1	LOC2
Comb	100%				
GLB1	96%	100%			
GLB2	87%	83%	100%		
LOC1	90%	94%	77%	100%	
LOC2	89%	85%	88%	79%	100%

Our study proved a high correlation between alternans of T amplitude (GLB1 and LOC1) and the alternans of T wave complexity index (GLB2 and LOC2). For example the two indices were in agreement in 83% and 79% in the global and local detection respectively.

Table 4 shows the Challenge scores of the 5 methods. The Combined method reach the highest score, 0.890, which is the second best in the Challenge. It turns out that all the tested methods reach a higher score than 0.800, which is a satisfiable performance. In addition, in the

Table 3. Correlation coefficient between the 5 different methods of TWA detection: Comb (Combined), GLB1 (Global T amplitude), .GLB2 (Global PCA_T), LOC1 (Local T amplitude), and LOC2 (Local PCA_T).

	Comb	GLB1	GLB2	LOC1	LOC2
Comb	1.00				
GLB1	0.90	1.00			
GLB2	0.67	0.58	1.00		
LOC1	0.70	0.80	0.40	1.00	
LOC2	0.66	0.56	0.63	0.46	1.00

Table 4. Scores of the 5 methods of TWA detection: Comb (Combined), GLB1 (Global T amplitude), .GLB2 (Global PCA_T), LOC1 (Local T amplitude), and LOC2 (Local PCA_T).

Method	Score
Comb	0.890
GLB1	0.861
GLB2	0.802
LOC1	0.831
LOC2	0.812

Table 5.List of records with positive TWA detection with the Combined (Comb) method.

twa01	twa32	twa73
twa06	twa33	twa79
twa09	twa34	twa82
twa13	twa50	twa88
twa15	twa51	twa91
twa17	twa64	twa97
twa21	twa67	twa98
twa25	twa69	
twa29	twa72	

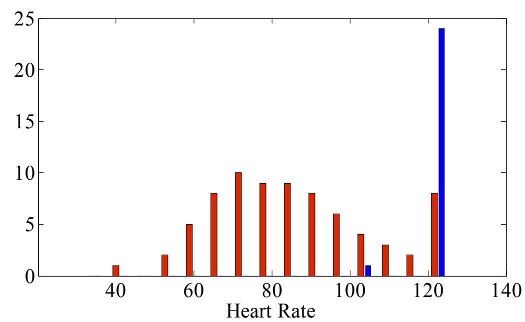

Figure 2. Histogram of heart rate in patients with (blue bars) and without (red bars) the presence of TWA determined by the Combined (Comb) method.

case of T amplitude, the global method achieves a better result than the local method, while the contrary is true for the PCA index. Table 5 reports the list of all the ECG records with the presence of TWA considering the Combined method, and Figure 2 shows the histogram of the heart rate.

4. Discussion and conclusions

The task of TWA detection has been studied considering two parameters in the time domain: the T wave amplitude computed in a combined lead, and the complexity index of the T waves. The classification has been performed analyzing the entire ECG records or a set of intervals. The results show that the combined algorithm has the best performance, as it could be expected in general. The parameters considering the T amplitude have a higher performance compared to the T wave complexity index based on PCA. However, the two parameters showed a good agreement between them, and there was less score differences in the local methods.

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