Principal Component Analysis Based Method for Detection and Evaluation of ECG T-Wave Alternans

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Abstract

The method for detection and evaluation of T-wave alternance in ECG was elaborated for monitoring of the status of the patients in the Intensive Care Unit of Cardiology Clinics. 24h ECG recordings registered mostly in patients after myocardial infarction were used for elaboration of the method. Data preprocessing included ECG structural analysis, respiration and/or other factors caused baseline wander removal and T-wave duration correction using modified Bazett's formula. The arrays of samples representing T-wave of one cardio cycle in all ECG leads were concatenated into one array. Such arrays from all cardiocycles formed two dimensional array of samples, representing all samples of T-waves of all cardio cycles in the recording. Principal component analysis method was used to reduce the dimensionality of the set of samples, concentrating representation of interrelated variables into principal components. T-wave alternance usually was represented by one or mostly by few principal components. Amplitude of specific alternance of the coefficients of these principal components used to represent T-wave of every cardio cycle gives the quantitative estimate of the phenomena. Cluster analysis of these coefficients could reveal the variety of T-wave morphology during T-wave alternance. The method was tested on the ECG recordings from CinC/Physionet Challenge 2008 database.

1.   Introduction

The main tasks of Clinical Decission Support Systems for Intensive Care Unit of Cardiology Clinics is evaluation and prognosis of the status of the patient. Timely taken actions can save the life of critical patients. Long term recordings and analysis of biomedical signals reflecting heart function and central hemodynamics showed their usefulnes since decade or more [1]. Rapidly increasing available computation power inspired development of new analysis methods, enabling to reveal new parameters for evaluation and prognosis of the status of the patient. T-Wave Alternance (TWA) is reported to be a reliable predictor of ventricular sudden cardiac death (SCD) [2], so detection and evaluation of it could reveal a new possibilities for the clinicians. Multivariate analysis methods, such as Principal Component Analysis (PCA) are successfully used for evaluation of morphology changes in quasiperiodic biomedical signals [3]. The aim of this study was to show how PCA applied for sequence of ST-T segments can detect and evaluate TWA.

2.   Methods

Chest leads of ECG were recorded during 24h follow up of the patients in acute phase of myocardial infarction (Permission of Kaunas Region (Lithuania) Ethics Committee for Biomedical Research Nr. 169/2004) using "HeartLab" system [4]. Recordings were made using 12 bit resolution and 500 Hz sampling rate. We selected ECG recording episodes free of extrasystolic beats, and visible registration artifacts. Signal preprocessing we started with detection of fiducial point of each cardiocycle – R-wave. After preliminary detection using filtered derivative of the ECG signal we maximized cross-correlation of the sliding in time R-wave template with the ECG signal. R-wave template was constructed from first 5 cardiocycles of the recording and updated after every processed cardiocycle. A value of short interval between the end of T-wave of preceding cardiocycle and beginning of P-wave of current cardiocycle, evaluated as a mean of 10 consequent samples starting from 170th ms before the fiducial point was considered to be a baseline reference point of each cardiocycle. Bicubic spline interpolation using these reference points was used to calculate baseline wander component, which was subtracted from the original signal in each lead. The 160 samples starting from 22nd sample after fiducial point were considered as reflecting repolarization process in each cardiocycle (ST-T complex). The length of QT interval is depending on heart rate. We applied time stretching of the ordinary ST-T interval using bicubic spline interpolation, maximizing cross-correlation with the template constructed from the first 10 cardiocycles. Estimated coefficients for QT interval time stretching were close to the values reported

by Sagie et al.[5], proposed as substitution of classical Bazett formula. Corrected (stretched) arrays of samples from each registered lead of the same cardiocycle were concatenated together forming one array. The concatenated arrays of all cardiocycles formed matrix of samples *X*, which was giving a redundant but comprehensive representation of variety of the shape of ST-T complexes from the recording considered for analysis:

$$\mathbf{X} = \begin{matrix} x_{1,1} & x_{1,2} & ... & x_{1,n} \\ x_{2,1} & x_{2,1} & ... & x_{2,n} \\ ... & ... & x_{i,j} & ... \\ x_{p,1} & x_{p,2} & ... & x_{p,n} \end{matrix} , \qquad (1)$$

where $x_{i,j}$ is the ith sample of the jth cardiocycle. The principle component analysis (PCA) was used to reduce dimensionality of this representation. The PCA transforms the original data set into a new set of vectors (the principal components) which are uncorrelated and each of them involve information represented by several interrelated variables in the original set. The calculated principal components are ordered so that the very first of them retain most of the variation present in all the original variables. Thus it is possible to perform a truncated expansion of ST-T complexes representing vectors by using only the first several principal components. Every vector x_i representing ordinary ST-T complex is then represented by linear combination of the principal components ϕ_k multiplied by coefficients $w_{i,k}$:

$$\mathbf{x}_i = \sum_{k=1}^{p} w_{i,k} \varphi_k . \qquad (2)$$

Variation of coefficients $w_{i,k}$ represents variation of the shape of ST-T complexes. We expected that TWA should be represented by beat-to-beat variation of one or at least few coefficients. So far TWA is reported as beat-to-beat variation of ST-T complex shape (or amplitude), only the highest frequency variation of the coefficients should be considered for evaluation.

The method was also tested on the ECG recordings from CinC/Physionet Challenge 2008 database.

3. Results

Concatenated array of ECG ST-T complexes from twelve leads of ordinary cardiocycle are presented at the top of fig.1. First ten principle components calculated from all concatenated arrays of ST-T complexes of this recording are presented on fig.1 below the ST-T complexes. Percentage of variation of ST-T complexes in this recording represented by principal components is presented in fig.2 together with Wold's cross-validatory estimation criteria PR used to determine the minimal

number of components in principal component models [6]. As one can see, first 5 principle components were representing 99.54% of variation, however according to our experience in determining minimal, yet sufficient, number of principal components (optimal basis functions) for truncated expansion of electrical signals from the heart [7] we decided to use first 10 principal components for further analysis (the curve of Wold's criteria has characteristic discontinuity at the 10th principal component).
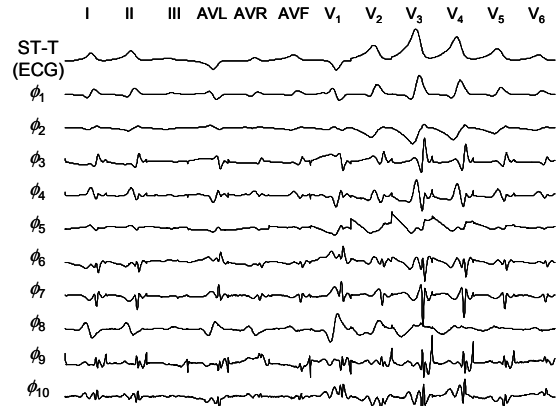

Fig.1. Concatenated array of ECG ST-T complexes from twelve leads of ordinary cardiocycle and first ten principle components calculated from all concatenated arrays of ST-T complexes of this recording.
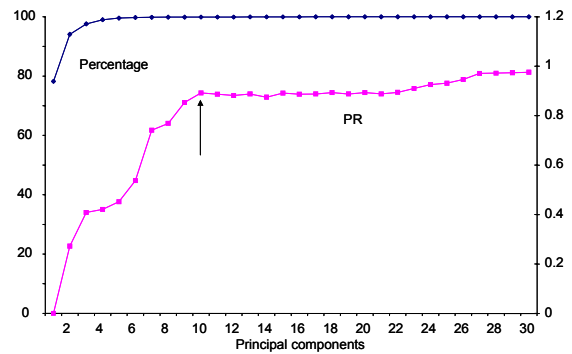

Fig.2. Percentage of variation of ST-T complexes represented by principal components and Wold's cross-validatory estimation criteria PR used to determine the minimal yet sufficient number of components in principal component models.

As we expected, there were specific alteration of values of one, or in some cases few, coefficients of first principal components in the recordings, where TWA was visually noticeable. Figure 3 illustrates values of coefficients of first 10 PC in the recording where TWA was present (A), and in the recording where TWA was absent (B). We found that values of coefficients of some

recordings are forming the separate clusters when depicted in orthogonal space (Fig.4). It means that the shape of ST-T complex is altering between some basic shapes. These basic shapes could be determined using coordinates of the centers of the clusters as coefficients of principal components for calculation.
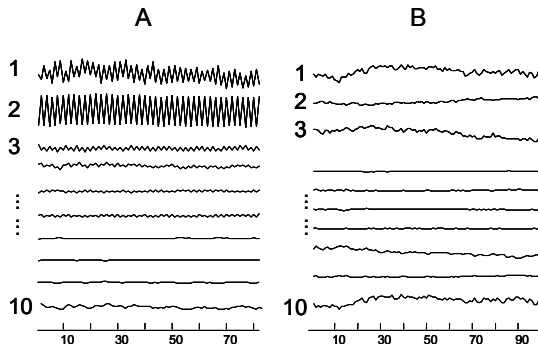

Fig.3. Values of coefficients of first 10 PCs in the recording where TWA was present (A), and in the recording where TWA was absent (B).
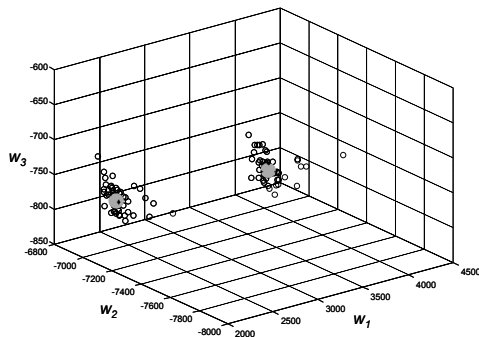

Fig.4. Values of coefficients of first three PCs forming the clusters.

Competitive Neural Network realized in MatLab[TM] was used to determine values corresponding to the centers of the clusters. Two basic shapes are shown on fig.5. It is interesting that TWA in many cases was not the alterations in amplitude equal in all leads, or proportional to the maximal amplitude in the lead. Shapes in some leads remain stable while others are changing substantially. We found even three separate clusters determining basic shapes in some recordings, but bigger number of clusters was always related with noisy signals and some registration artifacts. There were also recordings in which no distinct clusters of coefficients were determined, but TWA was present.

We used normalized estimate of power spectral density of the coefficients at the highest frequency as qualitative estimate of TWA. The value was considered only in cases when it was at least two times bigger then mean of 10 neighboring lower frequency estimates.

4. Discussion and conclusions

Alterations in ventricular repolarization observed as TWA phenomenon are reflected in multilead ECG recordings in redundant but comprehensive way. PCA applied to the assembly of ST-T segments from all registered ECG leads concentrates variation of interrelated between each other parameters, reflecting ST-T shape changes, into few principal components, giving the optimal representation of it. One can expect only one principal component reflecting TWA, but we found from one, up to three, rarely four principal components reflecting beat-to-beat ST-T shape changes in the recording. It means the alterations could have more complex background as expected. So, further physiological investigations needed to clarify the mechanisms of the phenomena, determining the shape of the signals.
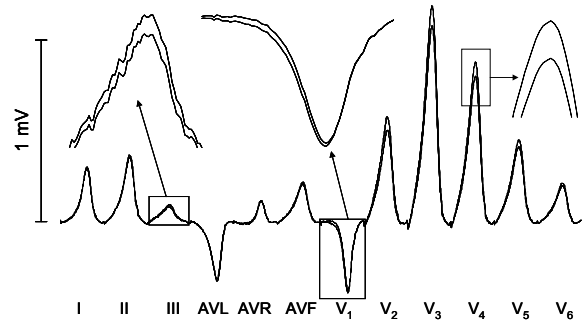

Fig.5. Basic shapes of TWA determined using coordinates of the centers of the clusters as coefficients of principal components.

We also found a lot of changes in ST-T shape caused probably by other factors than TWA, what interferes with beat-to-beat alterations in ventricular repolarization. Improvement of ECG signal pre-processing, extraction of pure ST-T segment, in many cases was reducing amount of false-detected TWA. So, signal pre-processing is very critical in this case. PCA reveals not only amplitude, but also detail shape changes of ST-T complex during TWA. We observed different character of changes in particular leads of multilead ECG recording. Amplitude of beat-to-beat alterations of coefficients of principal components is a linear estimate of amplitude changes, but, depending on the values in the array of particular principal component, it is different in various places of the ST-T complex and the lead. It also can't be compared between the recordings, because the principal components are calculated for one particular recording. Attempts to construct universal principal components by pulling the data from many recordings failed because of too big variety in ECG morphology between the patients.

In conclusion we can say that multilead ECG analysis

including PCA of ST-T complexes is a powerful tool in Clinical Decission Support System for Intensive Care Unit of Cardiology Clinics for evaluation and prognosis of the status of the patient.

Acknowledgements

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