Poincare Mapping: A Potential Method for Detection of T-wave Alternans

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Abstract

T wave alternans (TWA) at microvolt level is recognized as an important marker to predict sudden cardiac death and several methods are used to measure the variation of T-wave morphology. The purpose of this study is to assess the accuracy and effectiveness of Poincare mapping (PM) which is a method based on nonlinear dynamics in detection of TWA. Sample series selected from ECG were used to draw the Poincare maps from which we can get the different shapes and quantitative measures, alternans distance ($D_{\text{tw}}$). At the same time, these sample series were assessed by the spectral method (SM) and alternans voltage ($V_{\text{tw}}$) was obtained. Then the two kinds of measures were compared by linear regression and the correlation coefficient was $\gamma = 0.984$ which showed the significant correlation between them. The value of $D_{\text{tw}} > 20 \mu V$ was accepted as a level determinative for presence of TWA. The Poincare mapping was useful and potential for the detection of TWA.

1. Introduction

Recent researches indicate that the incidence of sudden cardiac death (SCD) is still increasing with lower average onset age. And Ventricular arrhythmias are one of the primary causes of it. As an important non-invasive index reflecting Ventricular arrhythmias\cite{1-2}, the microvolt T-wave alternans (MTWA) is closely related with SCD. TWA is defined as beat to beat variation of T-wave morphology and/or polarity at constant heart rate\cite{3}, which means the morphology and/or polarity change in ABAB form\cite{4}. The methods with pathologic significance of detecting MTWA have certain development and are divided into

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three kinds: Short Time Fourier Transform (STFT), symbol transform and nonlinear methods\textsuperscript{[5]}. The Spectral method (SM) which is one kind of STFT is the most mature. This paper presents a method based on nonlinear dynamics theory—the Poincare maps (PM) and compares the result with that of Spectral method. The result is proved to be of high consistency according to the correlation test.

In this paper, it adopted marr wavelet transform which was based on the algorithm a-trous to select feature points form ECG, and Bazzet formula was used for improving the T-wave analysis window. Then Spectral Method and Poincare mapping were carried out on detecting TWA, and we can get the figures of simulation results of power spectra and Poincare maps and their quantitative indexes: $V_{\text{twa}}$ (of SM) and $D_{\text{twa}}$ (of PM). This algorithm was applied in European ECG ST-T database and MIT/BIH Arrhythmia database, and the cross-correlation coefficient between $V_{\text{twa}}$ and $D_{\text{twa}}$ is $\gamma=0.9845$. The algorithm can be a simple method for detection of TWA and provide idea for further study of TWA-PM.

2. Methods

2.1. ECG preprocessing

First of all, the measured ECG S was filtered, in this paper, integral coefficients was used to eliminate power-line interference, and then the signal was filtered using threshold denoising algorithm by applying bior2.2 wavelet. In accordance with the a-trous algorithm, the marr wavelet transform was carried out in one to four scales and $a_j, d_j$ ($j=1,2,3,4$) can be observed. The $a_j$ represented wavelet detail part, while $d_j$ represented wavelet approximation part. Marr wavelet is second derivative wavelet basis, so the peak points after being transformed were the same as those in the original signal.

The maximum energy of QRS wave was in the $d_3$ scale, so R peak points were marked in the $d_3$ scale. Revising these points on the original signal within a predetermined time span and R peak points were finally obtained. Other peak points were found in such a way that in a 200ms window before R peak, Q peak was determined, while in a 100-350ms window after R peak, T peak was determined\textsuperscript{[6]}. All the peaks are shown in Fig. 1(*).

![Feature points about electrocardiogram signal S](image)

In order to detect MTWA more accurately, this paper adopts a T wave analysis window method that N=128 ECG complex were selected for TWA measurement and there were m=7 sampling points in every cardiac cycle\textsuperscript{[7]}. The starting point of the T-wave window was located at $\Delta t=50$ ms after the R peak and Bazzet formula was used for determination of the point terminating the T-wave analysis window as:

$$QT=k\sqrt{RR} \quad k=0.39 \pm 0.05 \quad (1)$$

The T wave window was divided into m (this paper m=7) equal parts, and every part was the sampling interval ID. So the sampling point $b_i$ can be obtained as formula:
\[ b_{i+1} = b_i + i \cdot ID \quad i=1,2,...,6 \] \hspace{1cm} (2)

2.2. Spectral Method

Spectral method (SM) is a method of turning the indistinguishable subtle changes to evident changes which was introduced by Cohen and his colleagues[8], and it has been the most standardized and mature method of detecting TWA[9]. SM adopts orthogonal lead system to extracting ECG signal. When the signal is recorded, heartbeat is accelerated to a degree by pacemaker or sports. The signal extracted from lead X, Y, Z are \( X_x(n), X_y(n), X_z(n) \), according to the formula synthetical lead signal can be get as \( X(n) = \sqrt{X_x^2(n) + X_y^2(n) + X_z^2(n)} \). The recordings including 128 consecutive beats were selected for TWA measurements, and locations of the T peaks and R peaks alignment are chosen to set T-window. N points from every T-window form a 128*N analysis matrix, then short-time Fourier transform (STFT) was used for analysis of all sample points and spectrum image was obtained.

Spectral method is one of the most widely used procedures for measurement of microvolt TWA. Superposition method was used to improve the signal noise ratio and to get more noticeable TWA in the power spectrum. Then the power spectrum of sampling points in N ST-T cardiac cycles were obtained by FFT as:

\[
P_{i+1} = \frac{1}{N} \sum_{i=1}^{N} \sum_{n=0}^{N-1} b_i W_N \left[ \sum_{n=0}^{N-1} \right] 0 \leq i \leq 127, N=128
\] \hspace{1cm} (3)

The power within 0.44~0.49 band was considered as background noise[10], of which the mean noise power was \( S_{nb} \), while \( S_{0.5} \) was the power at 0.5 cycles/beat, By above knowable, the power of TWA \( S_{twa} \) was defined as:

\[
S_{twa} = S_{0.5} - S_{nb}
\] \hspace{1cm} (4)

We make a rule in such a way that if \( S_{twa} < 0 \), there was no TWA and \( V_{twa} = 0 \), On the contrary, if \( S_{twa} \geq 0 \), there was TWA and the alternans voltage was obtained as \( V_{twa} = \sqrt{S_{twa}} \). Then, the Fourier spectrum was computed for a time series constructed of same phase samples taken from consecutive T-waves. Elevated peak at alternans frequency \( f_{0.5} \) (i.e., at half the heart-rate frequency) indicated TWA (Fig. 2).

![Fig. 2. Absence and presence of T-wave alternans power spectrum picture](image-url)
2.3. Poincare Method

The Poincare mapping is a technique, rooted in non-linear dynamics theory, that is particularly useful for inspecting stability of systems displaying periodic behavior\(^{[13]}\). According to the application of non-linear dynamics theory in nonstationary feature point recognition, Ruta\(^{[12]}\) introduced the PM method for detecting TWA in 2001. The quantitative indexes would be got and a statistically significant correlation exists for the analyzed ECGs between the TWA levels computed by means of an inter-cycle synchronize sampling technique.

Poincare mapping was compared with SM which was universal application and the correlation analysis showed the effectiveness of PM. When the sequence of feature point \(p=\{x_1,x_2,...,x_i,...\}\) was known, the Poincare maps could be drawn in two ways: one was constructed by \(x_i\) vs \(x_{i+1}\), the other was constructed by plotting second-order different plots \((x_{i+2}-x_{i+1})\) vs \((x_{i+1}-x_i)\) where \(i\) was the index identifying beat number\(^{[14]}\). The congregating distribution can be shown and the different shapes and quantitative indexes from which we can get the information we want.

According to the (1) and (2), \(7*N\) selected samples of T-wave can be get across \(N\) consecutive ECG cycles. We can also get a set of signal samples \(p=\{x_1,x_2,...,x_i,...\}\) form which a new sequence with subtraction between adjacent samples \(Q=\{x_2-x_1,x_3-x_2,...,x_i-x_{i-1},...\}\), its odd term \(N=\{x_2-x_1,x_4-x_3,...,x_{2i}-x_{2i-1},...\}\) and even term \(M=\{x_3-x_2,x_5-x_4,...,x_{2i+1}-x_{2i},...\}\) can be obtain. A simple distance measure between clusters to quantify TWA by means of Poincare map is proposed:

\[
D_{\text{twA}} = \sum 2 |E(M) - E(N)| = 2 \sum |E(N)|
\]

When alternans distance \(D_{\text{twA}}<20\mu V\), there was no TWA and \(D_{\text{twA}}\) was set to zero. When \(D_{\text{twA}} \geq 20\mu V\), TWA was present in the signal so \(D_{\text{twA}}=D_{\text{twA}}\). Poincare maps for T-wave detection are shown in Fig. 3\(^{[15]}\).

![Poincare maps for T-wave detection](image)

(a) No T-wave alternans ; (b) Presence of T-wave alternans

**Fig. 3.** Absence and presence for T-wave alternans Poincare mapping

### 3. RESULTS

In this paper, we used American MIT-BIH database and European ST-T database\(^{[16-17]}\). The sampling frequency in the former was 360Hz while in the latter 250Hz. For purposes of brevity, the signal from these databases was resampled with 200Hz so that the analysis became simpler. There were part of the simulation results as shown in Table.1 No 1-8 data were from MIT/BIH Arrhythmia database, and No 9-15 data were from European ECG ST-T database. All the data were from channel 1.
Table 1. Simulation data of some samples

| No | Recording number | Initial time(h:min:s) | Electrocardiogram | Spectral method Vtwa(μv) | Poincare maps Dtwa(μv) |
|----|------------------|-----------------------|-------------------|--------------------------|-------------------------|
| 1  | 101              | 00:00:00              | Normal            | 23.9224                  | 40.8534                 |
| 2  | 103              | 00:02:00              | Normal            | 8.2434                   | 32.4213                 |
| 3  | 107              | 00:10:00              | Paced beat        | 515.3927                 | 643.7407                |
| 4  | 111              | 00:02:00              | LBBB              | 100.8318                 | 141.4689                |
| 5  | 114              | 00:21:00              | Normal            | 61.2220                  | 68.6715                 |
| 6  | 115              | 00:02:00              | Normal            | 0                        | 0                       |
| 7  | 117              | 00:02:00              | Normal            | 75.0800                  | 89.6619                 |
| 8  | e0103            | 00:03:00              | ST change         | 93.4377                  | 137.7325                |
| 9  | e0103            | 00:37:00              | ST PVC            | 52.8216                  | 108.5577                |
| 10 | e0105            | 00:03:00              | ST and T Change   | 94.0732                  | 144.8165                |
| 11 | e0119            | 00:31:22              | ST and T Change   | 32.065                   | 26.83                   |
| 12 | e0124            | 00:30:00              | Normal            | 0                        | 0                       |
| 13 | e0125            | 00:03:00              | T Change          | 55.4030                  | 192.4842                |
| 14 | e0125            | 00:32:00              | T Change          | 175.3017                 | 246.6256                |
| 15 | e0126            | 00:03:00              | T Change          | 172.3274                 | 235.6344                |
| 16 | e0127            | 00:03:00              | T Change          | 74.7043                  | 146.8536                |
| 17 | e0129            | 00:39:00              | Normal            | 0                        | 26.4373                 |

From the above data, a significant correlation was found between the alternans voltage determined by the SM and the alternans distance calculated by the PM. The correlation was operated by least-squares curve fitting and a linear relation was found as following formula $D_{twa} = 1.1942 \times V_{twa} + 18.291$ in which the correlation coefficient $r = 0.9845$ (Fig. 4).
4. Discussion and Conclusion

According to the result of statistic, there was a strong correlation between $D_{twA}$ by PM and $V_{twA}$ by SM ($\gamma=0.9845$) that was a mature method of detecting TWA, so it was obvious that PM was also useful method. When PM was used, there can be some advantages. The number of the analyzed ECG complex can be much lower than the number required in the SM. By means of PM alternans the distance between any adjacent beats can be get which was more accurate and simpler.\textsuperscript{11} on the basis of this observation the value of the alternans distance, $D_{twA} \geq 20uV$, was accepted to determine presence of TWA by means of PM.

It is shown in a great deal of literatures that PM have been applied maturely to heart rate variability (HRV) test, but when it comes to detection of TWA, the related literature and research is little. Based on the inspiration got from the TWA-PM, further study can be done and other statistical quantitative indexes\textsuperscript{18-19} such as the area, the long axis(LA), the short axis(SA), the angle of long-axis and short-axis(ALS), vector angle index(VAI) and vector length index(VLI) can be gained. These characteristics seem to be useful for the detection of TWA, so they remain to be established.

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