T-Wave Alternans: A Comparison of Different Measurement Techniques

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Abstract

T-wave alternans (TWA) is characterized by a pattern of beat-to-beat alternations in the amplitude of the T-wave of the electrocardiogram (ECG). However, TWA is usually very small and hard to detect or measure. Our aim was to develop and compare three automated TWA measurement algorithms.

100 ECG recordings provided by the 2008 PhysioNet/Computers in Cardiology Challenge were analysed. After ECG pre-processing, moving four-beat window technique (FBW), Fast Fourier Transform (FFT) spectral analysis and principal component analysis (PCA) were used for TWA determination and quantification. These estimates were then ranked from 1 to 100, separately for each method, and the correlation between the results of each method analysed.

The correlation of the ranking of TWA estimates between FBW and FFT was 0.65, between FFT and PCA 0.33, and between FBW and PCA 0.24. With TWA criteria applied, the number of ECGs with TWA was for FBW 29, FFT 29, and PCA 38. Only 7 of the ECG records had TWA detected by all three techniques.

In conclusion, we have shown that different analysis techniques produced substantially different results.

1. Introduction

Sudden cardiac death (SCD) is a leading cause of mortality and remains a major clinical challenge. It accounts for 11% of all deaths and approximately 50% of all cardiovascular deaths [1]. A variety of non-invasive and invasive procedures have been studied to find markers of patients at high risk of SCD [2, 3]. Recently, T-wave alternans (TWA), also called repolarization alternans, has been proposed as a strong independent predictor of SCD [4, 5].

TWA is characterized by a pattern of alternations in the amplitude of the T-wave component of an electrocardiogram (ECG), where the even beats systematically display different amplitudes than the odd beats. However, overt and visible TWA in the ECG is very rare. Subtle and non-visible TWA at the microvolt level is much more common, and can only be measured with the help of computers [6, 7]. Therefore, advanced digital processing techniques and computational algorithms for measuring TWA are necessary.

Our aim was to develop and compare three different automated computational algorithms for detecting and quantifying subtle degrees of TWA in the ECG. This was undertaken as part of the 2008 PhysioNet/Computers in Cardiology Challenge.

2. Methods

100 ECG recordings sampled at 500 Hz with an approximate duration of two minutes from subjects with a variety of risk factors for SCD as well as healthy controls and synthetic TWA were analysed.

2.1. ECG pre-processing

ECGs were firstly pre-processed with a bandpass filter (0.5-20 Hz) to remove baseline movement and noise. This was followed by QRS and T-wave detection, including the detection of T-wave onset and offset points and its peak.

R-waves were detected using a double differential method. T-wave detection was achieved by setting a search window between two R-waves and finding the highest point. The onset and offset of the T-wave were found by working backwards and forwards from the T-wave peak to a point of inflection.

2.2. T wave analysis

Three algorithms were used for TWA determination and quantification. They were the moving four-beat window technique (FBW), Fast Fourier Transform (FFT) spectral analysis and principal component analysis (PCA).

For the FBW method T-wave amplitude changes in a four-beat window were calculated and averaged as the window moved through the data. For the FFT method the power spectrum of T-wave amplitude at 0.5 cycle/beat was calculated. And for the PCA method the first

principal component of T-waves was extracted and the FFT calculated for beat-to-beat change in coefficients of the first principal component.

2.3. TWA determination

For the FBW method the four-beat window was classified as containing alternans according to Figure 1, which shows the logical condition to be satisfied for classification. A data set was classified as TWA if more than 5% of windows contained alternans.

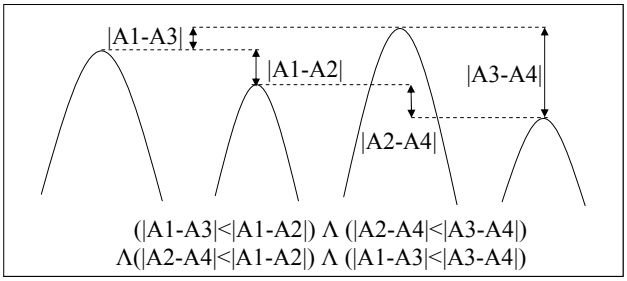

Figure 1. TWA determination rules for FBW method. A1, A2, A3 and A4 are the T-wave amplitudes calculated from beat 1, 2, 3 and 4 within the four-beat window.

For both FFT and PCA methods the magnitude of the peak at 0.5 cycle/beat was obtained as a direct marker of alternans. Meanwhile the alternans ratio (AR), which is the amplitude of the spectrum at the alternans frequency minus the mean background noise, divided by the standard deviation of the noise, was also calculated. AR >3.0 was required to classify positive alternans [5].

2.4. Correlation analysis

Alternans results for all 100 subjects were ranked from 1 to 100, separately for each of the three analysis techniques, and the correlation between the results of each method analysed.

3. Results

3.1. Representative example of TWA

Figure 2 shows one representative example with TWA determined by all three techniques. Figure 2(A) shows the T-wave amplitude changes alternately. Figure 2(B) gives the power spectrum of beat-to-beat fluctuation in the T-wave amplitude. The magnitude of the peak at 0.5 cycle/beat was 5532 with the AR of 839. Figure 2(C) shows the periodogram of the T-wave principal component, with the peak magnitude and AR of 0.00038 and 20 respectively.

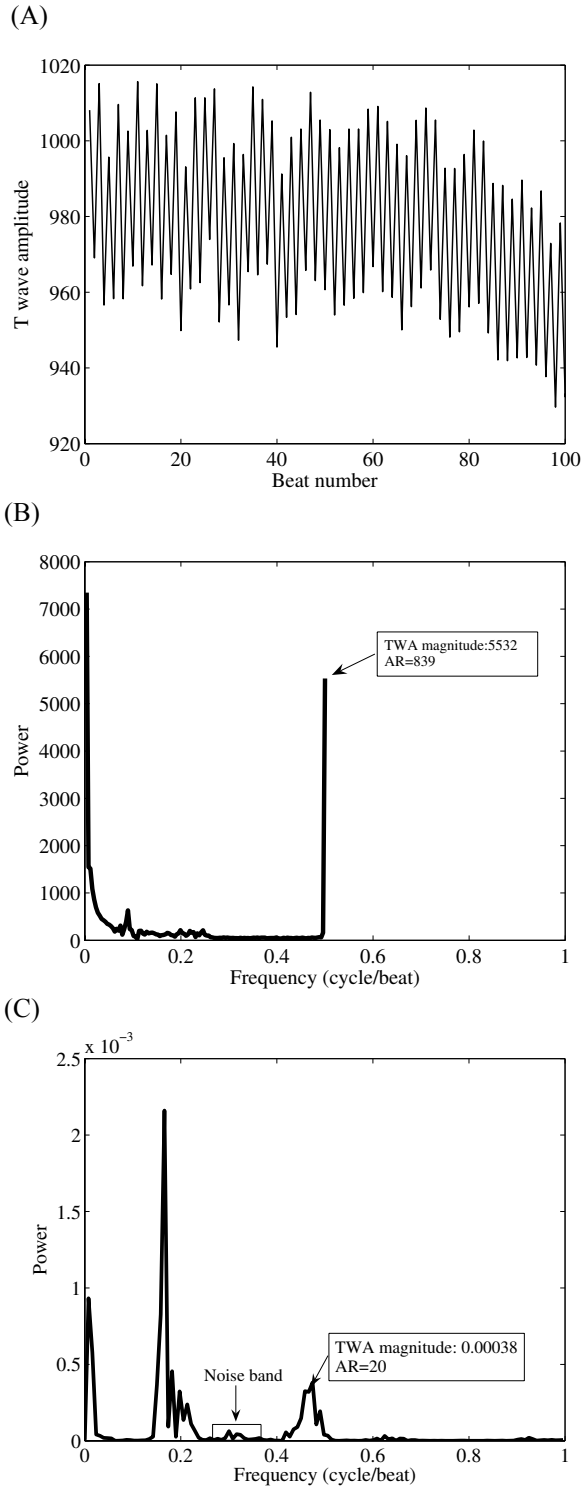

Figure 2. One example with TWA. (A) Beat-to-beat T-wave amplitude changes. (B) FFT spectral analysis. (C) PCA analysis. Units are arbitrary.

3.2. TWA determination and quantification

Figure 3 shows TWA estimates based on the above three methods. With the defined TWA criteria applied, the number of ECGs with TWA was for FBW 29, FFT 29, and PCA 38. 23 subjects were detected with TWA by both the FFT and PCA method, 11 by both the FBW and PCA, and 10 by FBW and FFT. However, only 7 of the ECG records had TWA detected by all three techniques.

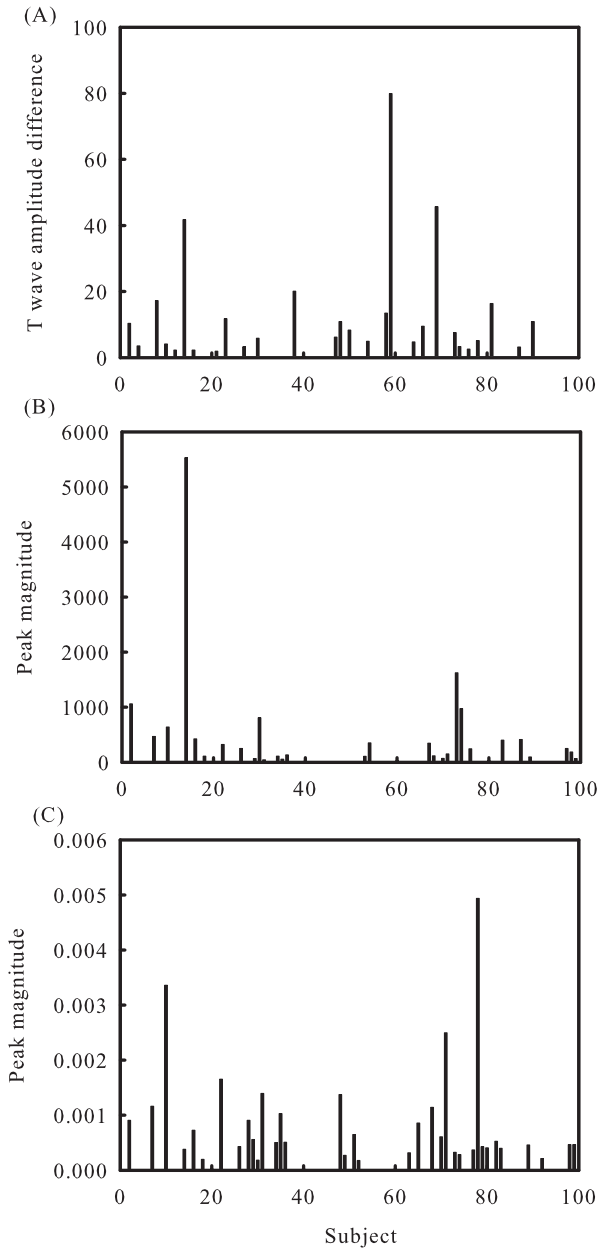

Figure 3. TWA estimates based on FBW (A), FFT spectral analysis (B) and PCA method (C).

3.3. Correlation of the ranking

The correlation of the ranking of TWA estimates between FBW and FFT was 0.65, between FFT and PCA 0.33, and between FBW and PCA 0.24, as shown in Figure 4.

3.4. Final scores

The final scores for FBW, FFT and PCA methods received for this challenge were 0.615, 0.827 and 0.779, where 1 is the best possible score and -1 is the worst possible score.

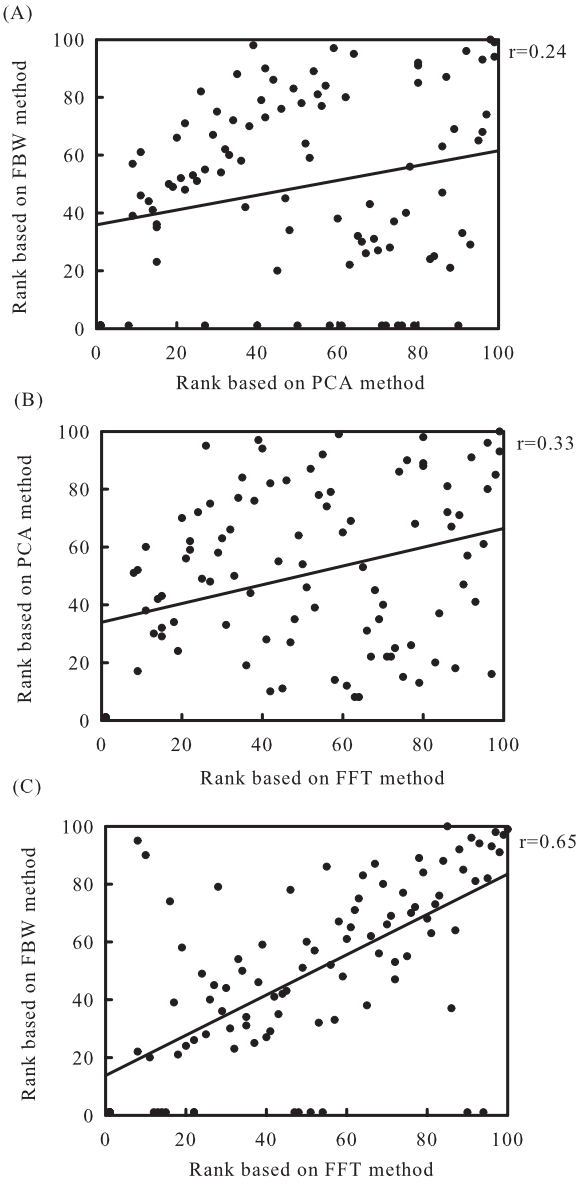

Figure 4. The regression analysis of the ranking of TWA estimates based on FBW, FFT and PCA method.

4. Discussion and conclusions

As expected, the majority of subjects (23/29>70%) with TWA detected by the FFT method have also been detected by the PCA method, because both of them are based on spectral analysis on the T-wave. But their agreement with time-domain analysis of TWA was very low. Therefore, the results presented here have shown that different analysis techniques produced substantially different results.

There needs to be further work to define TWA and to standardise TWA quantification methods, especially for features which could relate to cardiac disease.

Acknowledgements

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