Improving the Microvolt T-Wave Alternans Peak by Changing the T-Wave Search Window Duration

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Abstract

The microvolt T-wave alternans (MTWA) is a risk marker for sudden death. The classical method (CM) quantifies MTWA by detecting consecutive T-wave peaks. The Hilbert Transform approach (HT) quantifies MTWA with comparable performance and relies on concatenating successive T-waves. MTWA quantification depends on the T-wave search window (TSW). This work investigated the impact of variable TSW length in HT and CM. Fourteen ECG signals from Physionet T-wave Alternans Database were analyzed. Regular QT interval (QTr) was assessed using a triangle area approach. TSW was set from 100 ms after Q-wave to 25 ms after T-wave endpoint and tapered by a straight line connecting the extremes. TSW length was recursively shortened sample-by-sample, CM and HT were applied to every TSW, and alternans peak (AP) quantified. The TSW for the maximum AP was employed to calculate a putative QT interval (QTp). Maximal AP amplitude was compared between methods by correlation analysis. QTp and QTr were compared by Friedman's test. For AP and QTp, correlations between maximal AP and QTp were respectively, 0.92 and 0.85 ($p<0.05$). QTr vs. QTp correlations for CM and HT were, respectively 0.71 and 0.71 ($p<0.05$). QTp-CM and QTp-HT were equivalent, and both larger than QTr. AP is maximized after the T-wave endpoint, indicating an optimal TSW for MTWA.

1. Introduction

Microvolt T-wave Alternans (MTWA) is a phenomenon regarded as a beat-by-beat transmural phase 3 gradient alternation, related to impaired intra-sarcoplasmic influx and efflux dynamics [1], [2]. It is considered as a risk marker of inducible malignant ventricular arrhythmia during electrophysiological testing and considered a valuable arrhythmia risk stratification tool [3]. MTWA is defined as a beat-to-beat variation on T-waves amplitudes [4] and its evaluation only needs few minutes of ECG data.

The classical method (CM) for MTWA quantification uses the Fourier transform of sequential T-waves peaks amplitude series and requires accurate detection of these peaks [3]. Alternative methods have been validated, such as the Hilbert transform approach (HT) [5]. In HT, the Fourier transform is applied to the envelope of concatenated sequential T-waves windows.

As HT relies on beat-by-beat T-Wave pattern alternation, MTWA quantification may depend on T-Wave search window (TSW) length. This work investigated the impact of the TSW length on alternans peak in HT and CM.

2. Methods

2.1. Database

For this study, fourteen 12-lead ECG records in sinus rhythm ECG records were obtained from the T-wave Alternans Database, available in the Physionet website [6], from five control and nine subjects at high risk for sudden cardiac death (SDC).

2.2. Preprocessing

Data pre-processing was applied to allow uniform signal quality across all analysed signals. It was carried out in three steps, as follows:

i) A low-pass second-order Butterworth filter with cut-off frequency at 30 Hz (commonly used in clinical practice for ECG analysis), to reduce both muscle and mains interference and maintain spectral characteristics of ventricular repolarization;
ii) QRS complex detection, which was carried out by using the absolute first order derivative method;
iii) Baseline drifting correction using a spline function, anchored at the midpoint of two seven-point windows on the T-P segment. Considering R-wave as a reference, the location of the windows was adjusted to every beat, proportionally to the duration of the immediately preceding RR interval.

2.3. T-wave Search Window Analysis

The T-wave is the representation of ventricular repolarization on the surface electrocardiogram (ECG) and is characterized as an upright low amplitude broad hump following the QRS complex. To properly analyse MTWA, the T-wave search window (TSW) was first set from 100 ms after Q-wave to 25 ms after T-wave endpoint (Figure 1). Q-wave was detected by reverse-time analysis from the R-wave peaks. T-wave endpoints were calculated by the Triangle's area approach, a simplification of the Trapezius area approach [7], [8]. This window was tapered by a straight line connecting its extremes. Over the tapered TSW, MTWA was assessed by CM and HT.

For CM, every peak corresponding to TSW was calculated in 128 consecutive sinus beats. The vector containing the peaks was then Fourier transformed and alternans peak (AP) was measured at 0.5 beats per cycle.

For HT, the 128 consecutive TSW were concatenated, and the Hilbert envelope was calculated. AP occurred at half the fundamental beat-cycle frequency of the envelope Fourier spectrum.

Pinning the onset point, TSW was recursively shortened sample-by-sample until the T-wave endpoint, and both alternans peaks were quantified to all TSW. The TSW endpoint corresponding to the maximal AP was employed to calculate a putative QT interval (QTp).

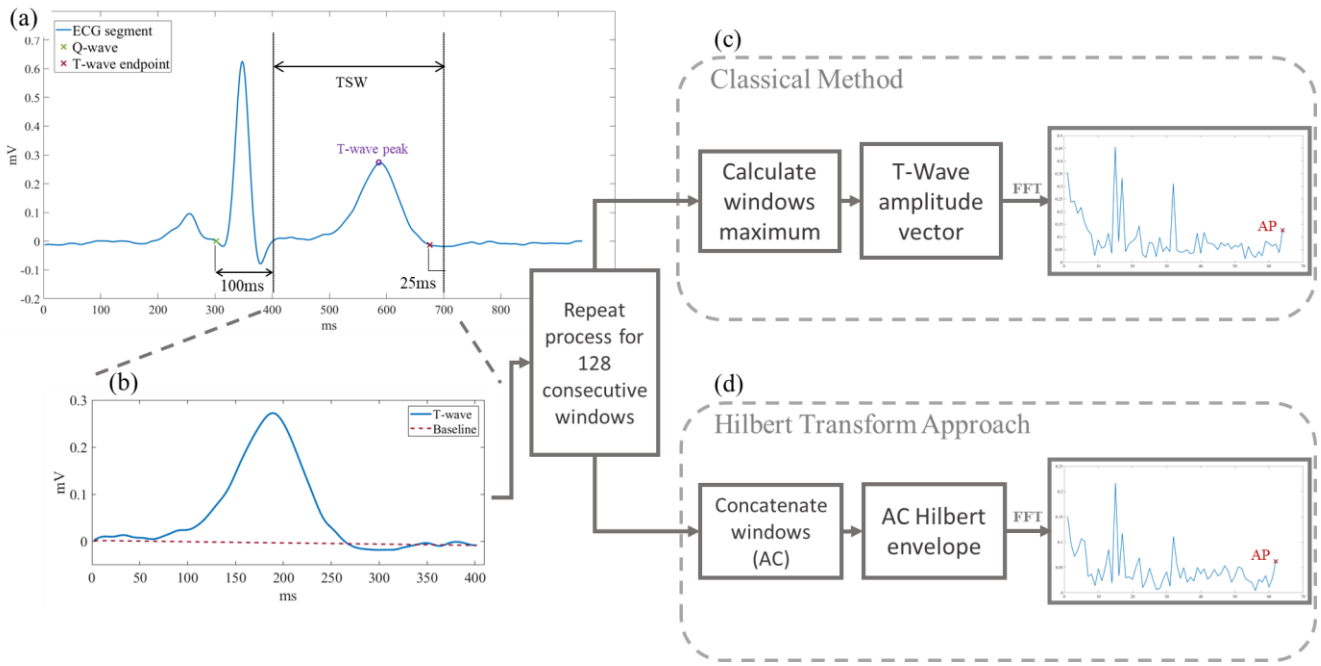

Figure 1. T-wave search window (TSW) analysis flowchart. (a) Referential TSW location, starting at 100 ms after Q-wave and ending 25 ms after T-wave endpoint (red dot). (b) TSW and its respective straight line (dashed red line) connecting its extremes for window tapering. (c) and (d) CM and HT algorithms sequence and alternans peak (AP) identification (red dots).

2.4. Statistical analysis

The alternans peak for CM and HT were calculated for all signals in all leads and numerical comparison was performed by boxplot charts and correlation analysis. Also, QTp and regular QT interval (QTr) calculated by the triangle area approach were compared by Friedman's test. The alpha error level was set at 0.05.

3. Results

The fourteen ECG records were successfully submitted for preprocessing analysis (Figure 2). Movement artifacts and electromyograms interferences were removed by low-pass filter application and baseline drifting removal provided stable baseline ECGs. Also, all 128 R-waves were correctly marked by the absolute first-order derivative method in all signals.

The MTWA was successfully calculated by both methods (CM and HT) for all signals and in all leads, using TSW. Although alternans peak amplitude in CM was different from HT [Figure 3(a)], it showed a high correlation between both (0.92; $p < 0.05$). Correlation of QTp between methods was also good (0.85; $p < 0.05$).

CM and HT-derived QTp showed nonsignificant differences but were larger than QTr [Figure 3(b)]. Correlations between QTr and QTp-CM, and between QTr and QTp-HT, were, respectively, 0.71 and 0.71 ($p < 0.05$)

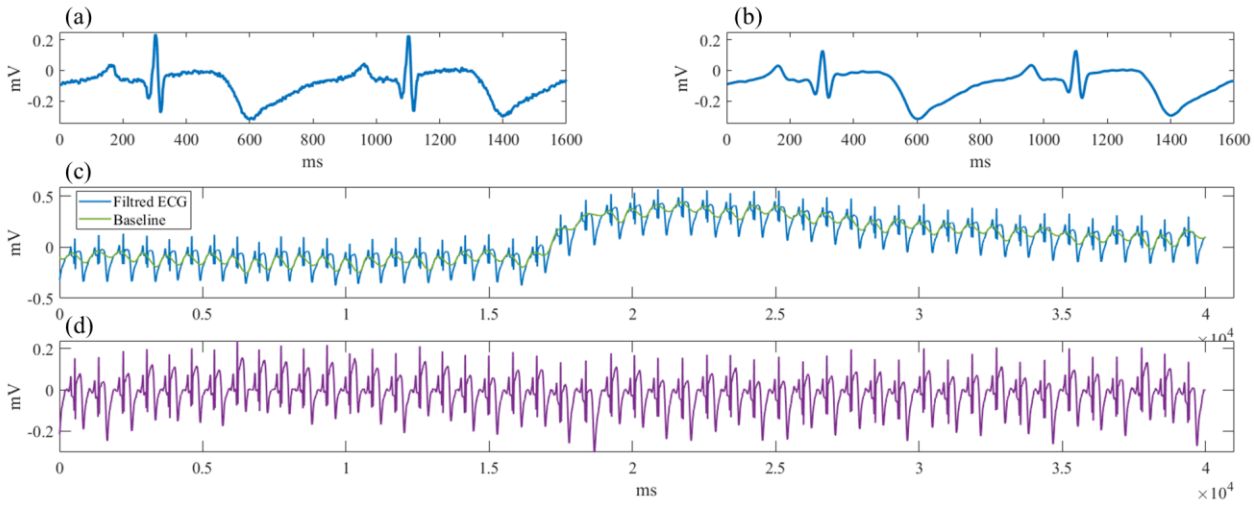

Figure 2. Results of data preprocessing for signal TWA40 (a) Segment of raw signal from database. (b) Same segment filtered by low-pass second order Butterworth filter. (c) Filtered ECG and its baseline calculated by two points in each T-P segment. (d) Result of baseline correction, baseline fluctuations were properly removed.

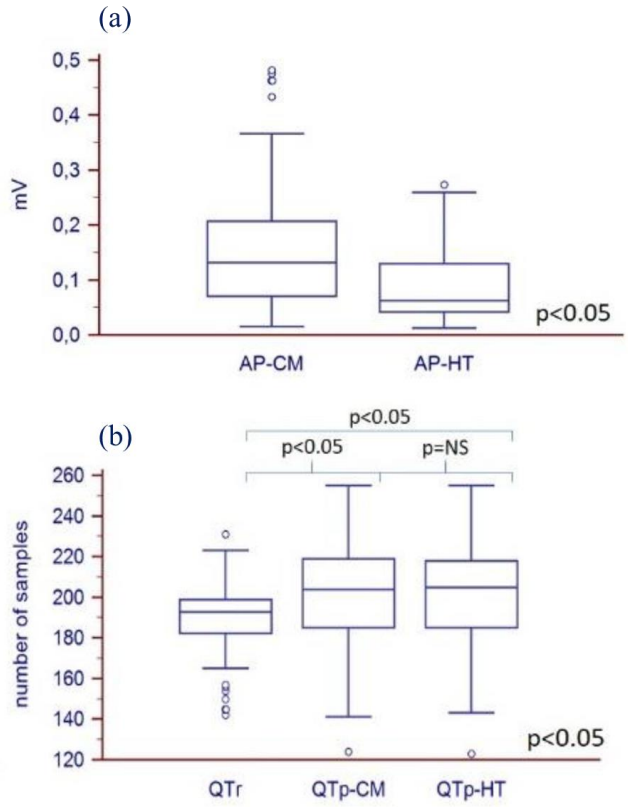

Figure 3. Boxplot for methods numeric comparison. (a) Results for AP in between CM and HT. (b) Comparison int between QTr, and QTp for CM and HT.

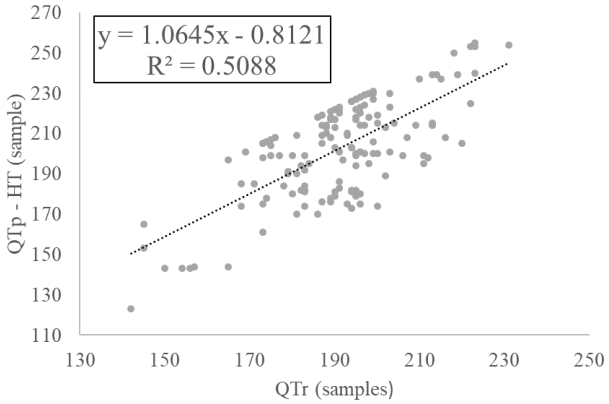

Figure 4. Correlation analyses for QTp-HT and QTr.

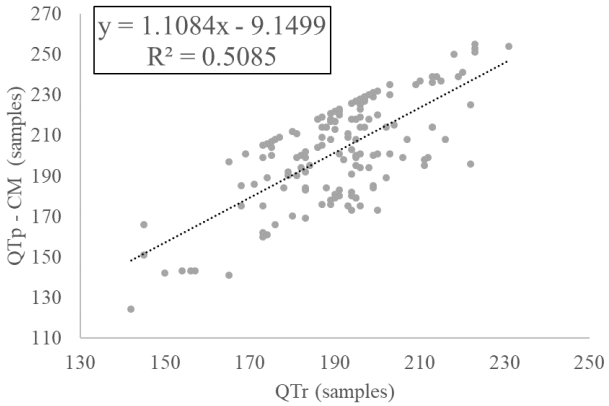

Figure 5. Correlation analyses for QTp-CM and QTr.

4. Discussion

Microvolt T-wave alternans quantification is an important tool in the search for properly assessing patients at risk for SCD. CM requires precise T-wave amplitude identification, and, thus, it is potentially affected by external interferences, such as noise and T-wave plateau variations [5], potentially affecting MTWA quantification. Alternative robust methods for MTWA evaluation, such as HT, are required to overcome CM limitation and to quantify adequately MTWA for SCD risk stratification.

This study investigates the impact of the T-wave search window on MTWA peak for CM and HT methods. By pinning TSW onset point and recursively reducing its length, it was found that there is a TSW length in which AP is maximized. The TSW at which AP was maximized was then used to calculate a putative QT interval (QTp). Furthermore, results showed that both methods CM and HT were well correlated to each other regarding to alternans amplitude. Although AP in CM was slightly but significantly higher than in HT, it did not compromise MTWA quantification and reproducibility [5]. Further studies are needed to investigate it.

QTp-CM and QTp-HT intervals showed to be larger than QTr, indicating that AP is maximized at a TSW larger than the proper QT interval. Thus, in both cases, an optimal TSW endpoint was located slightly after T-wave endpoint (24 ms), thus maximizing MTWA.

Some limitations of this work must be considered. The concept was applied only to real ECG signals, in sinus rhythm, to ensure appropriate CM quantization, which confined the analysis to 14 signals from the database. Studies with larger samples are required for clinical validation. Indeterminate MTWA was not assessed and remains a limitation in SCD risk stratification. Larger databases may also offer more precise information about proper TSW for MTWA quantization.

In conclusion, in MTWA analysis, displacing T-wave search window endpoint slightly further away from the regular T-wave endpoint maximizes microvolt T-wave alternans amplitude and has potential to improve both MTWA analysis and clinical application.

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