Baseline Drifting Removal Affects Microvolt T-Wave Alternans Measurement

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Abstract

Microvolt T-Wave alternans (MTWA) is a beat-to-beat alternation of T-wave and is considered an early marker of sudden cardiac death. In clinical analysis, baseline drifting and other interferences are expected, requiring preprocessing, such as baseline drifting removal by spline functions. This work focuses on the impact of this approach on MTWA assessment for real-world signals. The classical approach estimates a baseline signal using ECG fiducial points and subtracts it from the original signal. In this preprocessed signal, the classical approach vector (CAV) is assembled using the maximum value of a T-wave search window. As an alternative, the T-wave amplitude vector (AAV) is assessed by the difference between the T-wave peak and end, avoiding baseline drifting removal. The spectral method is used to evaluate MTWA. The alternans spectrum from CAV and AAV were compared by coherence analysis using the Fisher transform. Alternans peak and ratio were compared using the Pearson coefficient and T-test. The study at the alternation frequency showed statistically significant coherence between the AAV and CAV spectra (average 0.54). Both alternans peak and alternans ratio for AAV were higher than CAV, suggesting that AAV avoids CAV-induced artifacts that interfere with MTWA assessment and warrants further investigation.

1. Introduction

The Microvolt T-wave alternans (MTWA) is a marker that quantifies micro-level variation in consecutive T-waves, either in shape or in amplitude [1] in the surface electrocardiogram (ECG). MTWA is considered an early marker of sudden cardiac death risk [2] and has been shown as a tool to identify patients at risk for ventricular tachyarrhythmia events and ones who may benefit from implantable cardioverter-defibrillator [3],[4].

Methods to identify subjects at high risk of cardiac events are an essential tool to reduce cases of sudden cardiac death (SCD). Cardiac events, including malignant ventricular arrhythmias and SCD, have a crucial role in mortality around the world and are considered a global health issue [5]. Several studies support MTWA accuracy in predicting malignant ventricular arrhythmia and SCD [6], where elevated MTWA values at heart frequencies around 105-110 bpm can be considered positive markers of high risk for SCD [7].

The electrophysiological mechanism of MTWA relies on intracellular calcium cycling [8]. As the heart rate increases, the duration ratio of the systolic and diastolic intervals approaches unity, yielding T-wave amplitude alternation. In clinical practice, MTWA can be evidenced by using different exercise protocols [9]. Particularly in patients with heart failure, heart rate is targeted between 105-110 bpm to elicit MTWA [9].

During exercise, ECG signals are highly susceptible to baseline wandering, an additive form of low-frequency interferences, which challenges T-wave fluctuations at microvolt level detection [10],[11]. Thus, such studies suggest that a proper MTWA analysis requires baseline stability.

Removal of the baseline drifting has been considered a hallmark of ECG stability in signal processing. By estimating the ECG baseline fluctuation function and subtracting it from the original signal (the classical approach), an adequate "steady" ECG signal can be obtained. However, the impact of low-frequency interference removal on MTWA analysis is still open to investigation.

This work examines the impact of classical baseline removal in MTWA assessment on real-world signals. The classical approach was compared with an alternative method to assess T-wave amplitude fluctuation, which dispenses baseline drifting removal.

2. Materials and Methods

The real-world ECG signals from the T-wave Alternans Database were analyzed [12]. The database contains 100 multichannel ECG records sampled at 500 Hz, with 16-bit resolution at ± 32 mV, comprising 32 simulated ECG signals and 68 real-world ECG signals of patients at high risk for sudden cardiac death and control subjects. Only 12 ECG leads were included, and all leads were analyzed on all signals. The database was sorted by the amounts of TWA, with the signal ranked as 100 judged to contain the most TWA.

The ECG selection criteria also excluded signals with discontinuities, excessively noisy signals, or those showing less than 128 sinus consecutive beats. Of the signals selected by the criteria, 2/3 were ranked above 40; the lowest rank was 8, indicating that the selection presents some MTWA.

A filtering setup was applied to achieve uniform ECG preprocessing throughout the database signals: a low-pass, 2nd-order Butterworth filter with a cut-off frequency of 30 Hz (used in clinical practice) [10].

2.1. T-wave Amplitudes Vector

2.1.1. Classical Approach Vector (CAV)

For the CAV, the baseline drifting was removed using a third-order spline fitting, previously described [13]. The method was based on estimating the whole ECG wander by a spline function. Two points were set to anchor the spline function at each beat: the midpoint of two arbitrarily defined seven-point width segments in the T-P segment (Figure 1). The beginning of the T-P window was beat-to-beat corrected to the immediately preceding RR interval duration.

Baseline drifting correction was performed by deducting the estimated baseline from the ECG signal Figure 1).

The T-wave amplitude in the baseline uncorrected ECG was calculated as the absolute maximum within a 300 ms search window, starting at 100 ms after R-wave, considering that the baseline was zero. All the 128 T-wave peaks were calculated, and the CAV was assembled.

2.1.2. Alternative Approach Vector (AAV)

As an alternative, for each ECG signal, the T-wave amplitude vector was calculated as the difference between the T-wave peak and the T-wave endpoint. The T-wave endpoint was detected by a previously described method [14]. The T-wave peak was pinpointed as the maximum amplitude in a 300 ms window moved backward from the T-wave endpoint. Except for the filtering stage, no preprocessing technique was employed to assess the T-wave amplitude vector (Figure 2).

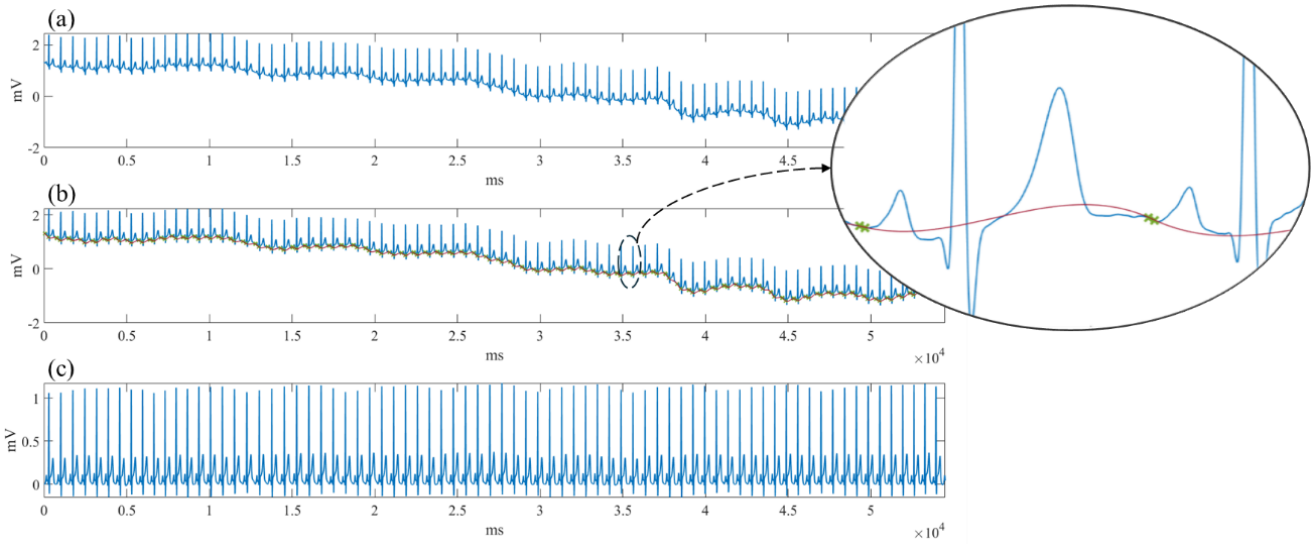

Figure 1 - Classical Approach Vector (CAV) for baseline-drifting removal. (TSC). (a) Original ECG from the database. (b) Estimating the baseline drifting using ECG fiducial points. In closer green points: the midpoint of two arbitrarily defined seven-point width segments in the T-P segment. The estimated baseline, in red, is calculated using a third other spline, interpolation on the green points. (c) The result of baseline drifting correction was performed by deducting the estimated baseline from the ECG signal.

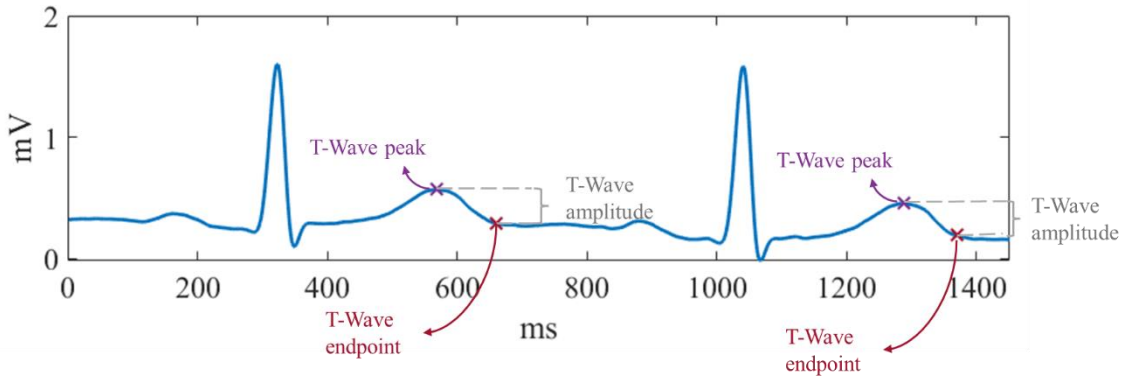

Figure 2- The alternative proposed approach vector (AAV) does not require baseline drifting removal. The T-wave endpoint (red 'x') is calculated, and the T-wave peaks are found (purple 'x'). The T-wave amplitude is the difference between the peak and the endpoint of the T-wave.

2.2. Microvolt T-wave Alternans Quantification

The CAV and AAV were assembled with 128 consecutive sinus-beat T-wave amplitudes and employed for MTWA quantification by the spectral method [1]. Each T-wave amplitude vector was Fast Fourier Transformed, and the MTWA spectrum for each technique was obtained.

From the spectrum of the MTWA, the Alternans peak was quantified as the spectral peak at the frequency corresponding to half of the whole T-wave series. 'Alternans ratio' (AR) was calculated as the Alternans peak divided by the Standard Deviation of ten consecutive harmonics in its neighborhood. Values above three units are considered abnormal.

2.3. Statistical Analysis

The alternans spectrum from both T-wave amplitude methods was compared by coherence analysis using the Fisher transform to ensure data normality (yielding a variable with approximately normal distribution and stable variance over different values).

The AR obtained from CAV and AVV was compared using the Pearson correlation coefficient and T-test and presented in box plots and bar charts.

3. Results

The spectral method for MTWA analysis criteria excluded 25 signals due to short duration and excessive signal-noise ratio in the T-wave region. The remaining 15 signals were successfully submitted to filtering and provided controlled noise signals. The AAV and CAV were estimated successfully for all the signals, and the MWTA spectra, alternates peak, and alternans ratio values were appropriately calculated for all signals.

After Fisher transformation, the mean coherence of both CAV and AAV was 0.51 ± 0.16.

The analysis of AR showed a low absolute correlation between the AAV and CAV methods, although statistically significant (0.256 p << 0,05). The mean alternans ratio for AAV was higher than CAV for each lead (Figure 3).

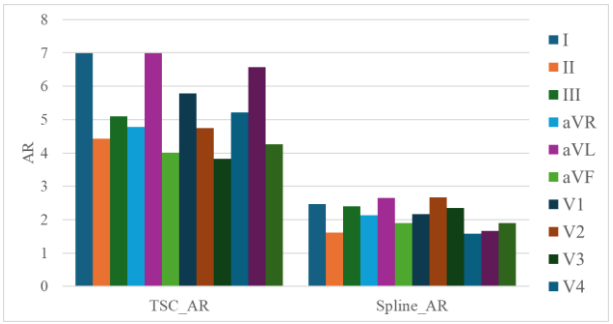

Figure 3 - Alternans Ratio for MTWA assessment methods, for each lead, in both methods. Noteworthy, in the CAV method, all AAV values were inferior to 3.0.

4. Discussions and Conclusions

Proper stratification of patients at risk of SCD is an essential task for predicting those at risk of fatal events and reducing the number of cardiac deaths worldwide. The MTWA is a promising tool with potential in the SCD risk stratification field. Considering that MTWA signals are settled in the microvolt level, these markers are highly susceptible to instrumentation-derived interferences, particularly those related to the ECG recording process. It is well-known that T-wave parameters are hard to estimate [6] because of wave shape and low-frequency characteristics. Thus, methods for accurate measurements of MTWA without introducing additional artifacts are highly required.

The AAV and CAV algorithms performed as expected,

providing proper T-wave amplitude series for analyses, and the MTWA spectra were successfully calculated. A low coherence was observed between the spectra generated from the CAV and AAV vectors. In addition, there was a 25% correlation for the alternans ratio between the methods, which indicates a relatively low amount of coincident information between the two methods. On the other hand, the results from AAV showed average values well above 3.0 for all leads, indicating that effectively MTWA was present. In contrast, results from CAV showed average values below 3.0 for all leads, indicating the predominance of no MTWA detections. In this regard, it can be stressed that the only difference between the analyses is the baseline removal step.

Despite being cited as a technique to avoid applying high-pass filters, removing the baseline using the fiducial point estimation method has a high-pass filtering effect, potentially modifying the T-wave's shape. Eventually, this modification could mask the MTWA measurement. We have identified that this phenomenon affected all CAV analyses. In clinical cases, these results would turn negative for MTWA, severely impacting risk stratification.

On the other hand, when analyzing the T-wave amplitudes in AAV, the signals showed MTWA (Figure 3). The main difficulty in obtaining AAV is appropriately identifying the end of the T-wave. This point was determined using [13] and tested on a real-world database with various wave patterns and noise. Furthermore, as this point is a temporal marker, it is possible to apply methods recommended in the literature for smoothing out noise and interference to identify this point. With the temporal markers, it is possible to return to the original signal and determine the amplitude of the T wave without needing more complex preprocessing.

In conclusion, our findings indicate that removing the baseline ECG wandering using a cubic spline MTWA quantification can be seriously affected. Spline-derived baseline correction alters T-wave amplitude alternation in the microvolt level in the ECG signals. Further studies are necessary to confirm the potential of AVV to be used in MTWA and its efficacy in clinical scenarios.

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