Baseline drifting correction for automated MTWA measurements

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Abstract

To reduce the incidence of sudden cardiac death (SCD), risk stratification markers have a relevant role. Microvolt T-wave alternans (MTWA) is a marker of SCD risk, defined as T-wave amplitude variation in the ECG. Usually, MTWA tests are carried out in noisy environments when interferences are expected. Baseline drifting correction methods may distort ECG signals, compromising MTWA analysis. This work assesses the impact of baseline drifting removal (BLDR) by two approaches. Signals with controlled baseline drifting, respiratory fluctuations and MTWA were analyzed. The classical BLDR approach (CA) estimates baseline signals using ECG fiducial points. The time-space cancellation approach (TSC) uses only T-wave information to assemble a vector with T-wave amplitudes, calculated by the difference between the maximum T-wave value and its endpoint. The squared coherence between the spectrum from each approach and the spectrum of the ECG without baseline drifting was calculated. At the alternation frequency (0.5 cycles-per-beat) a higher coherence occurred with TSC (0.57) as compared to CA (0.19). Results indicate that CA adds a distortion to the ECG, compromising MTWA. Conversely, the TSC approach preserves MTWA oscillations and has the potential to improve MTWA quantification.

1. Introduction

Simple and non-invasive methods for risk stratification are useful to identify subjects at high risk of cardiac events. Sudden (SCD) and unexpected cardiac death is a common cause of death worldwide, accounting for approximately 25% of all deaths [1]. This has a significant impact on economic, social, and health systems worldwide. Thus, techniques for identifying subjects at risk are highly desirable. Surface ECG analysis is a widespread diagnostic tool, and it has the potential to identify subjects with an elevated probability of cardiac arrest.

Microvolt T-Wave alternans (MTWA) is thought to reflect the alternation of ventricular action potential duration transmurally and is defined as a beat-to-beat alternation at microvolt level in the amplitude of the T-wave [2]. MTWA is considered an early marker of SCD risk [3] and has been shown as a useful tool to identify patients at risk for ventricular tachyarrhythmia events in diverse patient populations and may benefit from implantable cardioverter-defibrillator [4]-[6].

The electrophysiological mechanism underlying MTWA is based on the interdependence of systolic and diastolic intervals duration, interfering with intracellular calcium cycling [2]. Therefore, elicitation of MTWA depends on the instantaneous heart rate increment. In normal subjects, MTWA can be detected when the heart rate is above 120 bpm [7], whereas in patients with heart failure, MTWA can be elicited at a target rate of 105-110 beats per minute. It can be reached using a specialized exercise protocol on a treadmill or a cycle-ergometer.

The clinical environment where MTWA is usually recorded produces ECG signals susceptible to baseline wandering and interferences. These interferences originate from electrode respiration, perspiration, and body movements, especially during exercise stress testing. When measuring ECG parameters, baseline wandering may produce artificial information mainly on the ST segment [8]-[9]. Thus, a proper microvolt T-wave alternans analysis relies on baseline wandering removal.

This work assessed the impact of baseline wandering (drifting) removal for automated MTWA measurement. Two approaches were considered: I) The classical baseline drifting removal approach (CA), which estimates the baseline drifting signal using ECG fiducial points; and II) The time-space cancellation approach (TSC), that uses T-wave information to assemble a vector with T-wave amplitudes, calculated by the difference between the maximum T-wave value and its endpoint.

2. Materials and Methods

MTWA databases for proper analyses are limited and hard to find. Therefore, the employment of synthetic signals mimicking real-world ECG signals is a widespread alternative approach [10]-[12].

The ECG employed for analysis was synthesized using real-time parameters. A real ECG beat composed of P-wave, QRS complex, and T-wave was used as a basic unit. The amplitude of the T-wave was decreased by 5% on a separate ECG beat, and a duet ECG composed of a beat with normal T-wave followed by one with a lower amplitude T-wave was concatenated to compose a 128-beat ECG series. The synthesized signal is 1,5 minutes long, sampled at 200 Hz and 16-bit resolution at ±32 mV range. In this signal, a fixed respiratory fluctuation was added. A maiden ECG 128-beat signal with respiratory fluctuations and T-wave alternans was used for further comparisons.

Baseline drifting signals were extracted from T-wave Alternans Database ECG signals [13] using cubic splines [14] applied to the TP and the PR segments and added to the reference signal. This procedure comprised 28 different ECG signals with respective baselines drifting.

2.1 MTWA Analysis

MTWA was accessed using the spectral method [8]. A sequence of 128 T-wave amplitudes was extracted from each ECG signal, composing an amplitude vector. This vector was Fast Fourier Transformed, and the MTWA spectrum was obtained.

The MTWA spectrum was calculated for all ECG signals using both methods (CA and TSC). The spectrum from the ECG signal before adding baseline drifting (maiden ECG signal) was used for comparison.

2.1.1 Classical Approach (CA) for baseline-drifting Removal

The usual method for baseline drifting correction was described by [14]. It consists of estimating the ECG wander by a spline function. In the present study, the splines were anchored at the midpoint of two arbitrarily defined seven-point width segments in the T-P segment and before the Q-wave. Considering an R-wave as a reference, the beginning of the T-P window was beat-to-beat corrected to the immediately preceding RR interval duration (Figure 1 (a)).

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

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

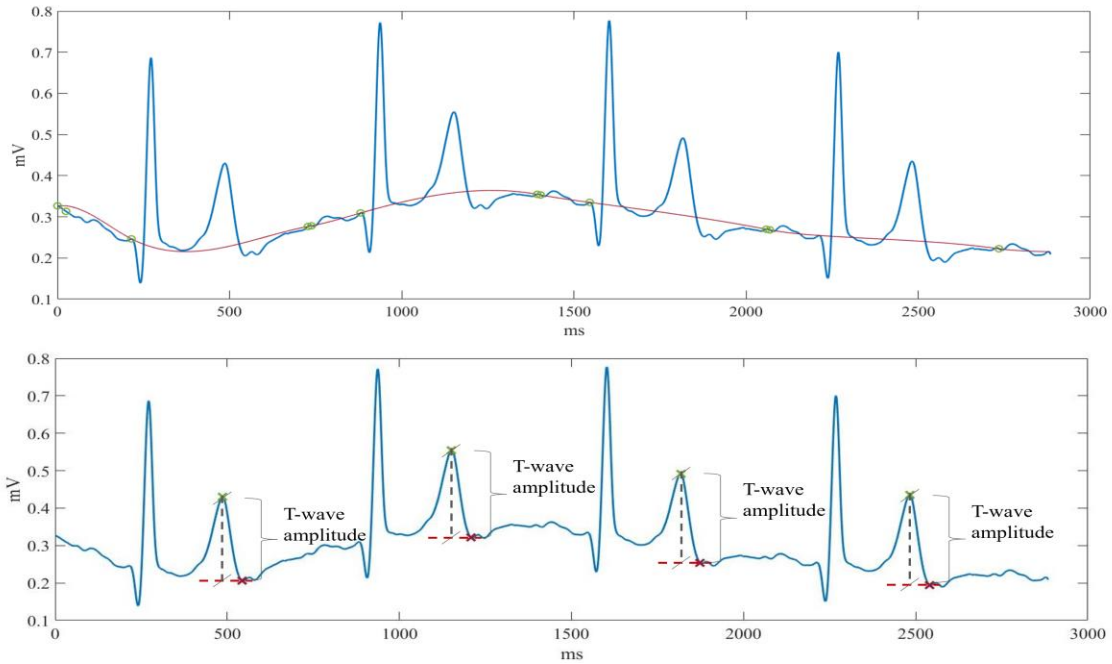

Figure 1. Classical Approach (CA) for baseline-drifting removal and Time-space cancellation approach (TSC). (a) ECG in blue is pinpointed with fiducial points (in green): the midpoint of two arbitrarily defined seven-point width segments in the T-P segment and before the Q-wave. The estimated baseline, in red, is calculated using a third other spline, interpolation on the green points. Baseline drifting correction was performed by deducting the estimated baseline from the ECG signal. (b) For TSC, only T-waves are taken into consideration. The endpoint of the T-wave (red 'x') is calculated, and the T-wave peaks are found (green 'x'). The T-wave amplitude is the difference between the peak and the endpoint of the T-wave.

2.1.2 Time-space cancellation approach (TSC)

In TSC both P-wave and QRS complex were neglected in every beat, taking only the T-wave into consideration for MTWA analysis. To calculate the T-wave peak amplitude, the T-wave endpoint was detected by the natural geometric approach [15]. Subsequently, the T-wave peak amplitude was pinpointed as the maximum amplitude in a 300 ms window moved backward from the T-wave endpoint. The corrected T-wave peak amplitude was the difference between the T-wave peak and the T-wave endpoint (Figure 1b).

2.4. Statistical analysis

The squared coherence between the spectrum of the maiden ECG signal and the respective spectra of CA or TSC pre-processed ECG methods were calculated. The coherences at the alternans frequency, 0.5 cycles-per-beat, in both CA and TSC methods were compared.

The coherences were transformed by Fischer transformation, to ensure data normality (yielding a variable with approximately normal distribution and stable variance over different values). The coherence at alternans frequency calculated with both methods were compared by paired z-test and box-plot charts.

3. Results

The application of 28 different real baselines drifting signals to synthesize ECG signals with MTWA resulted in a heterogeneous and robust set of ECG signals.

The CA and the TSC approaches were performed successfully and the MWTA spectra were calculated for all signals.

The mean coherence of the alternans frequency (Figure 2) was 0.11 ± 0.11 for CA and 0.52 ± 0.35 for TSC, after Fisher transformation.

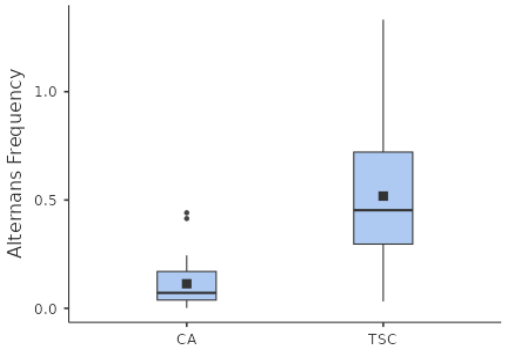

Figure 2. Box-plot results for the coherence in the alternans frequency for CA and TSC.

The p-value of the z-test for the different means of the two methods was 0.009.

The CA approach showed no coherence above 0.5 at alternans frequency. In the TSC approach, 43% of 28 ECGs had coherence higher than 0.5.

4. Discussions and Conclusions

Appropriate stratification of patients at risk of developing fatal cardiac arrhythmias is crucial for prophylaxis and treatment. While MTWA (Microvolt T-wave alternans) is a promising tool for arrhythmia risk stratification, its measurement is highly susceptible to interferences, including those caused by the ECG recording process itself. Therefore, methods that can accurately measure T-wave parameters without introducing additional artifacts are required.

Additionally, a synthesized ECG database is an alternative for the MTWA analyses, in a scenario where reliable annotated databases are limited and hard to find [10]-[12]. Thus, assembling data using real parameters allows proper evaluation of the parameters. In this study, we constructed a database by combining real ECG beats with various real baseline wanders, aiming to create data that closely resemble real ECG signals. It is important to note that using a synthetic database is a limitation of this work, and further research is required to validate this concept.

The CA and TSC algorithm performed as expected providing proper T-wave amplitude series for analyses. The MTWA spectrum was successfully calculated for all cases and provided comparison parameters for this analysis.

The results from the CA (classical approach) raised concerns, as it demonstrated a very low mean coherence (0.11 ± 0.11) in the alternans frequency. Additionally, no cases showed a coherence value higher than 0.5. These findings suggest that the CA approach may introduce changes in the ECG signal, which could potentially compromise MTWA analysis. It's worth noting that the literature also suggests that baseline drifting correction might introduce artificial information in ST segments when measuring their parameters [8].

In contrast, the time-space cancelation technique does not require any interference in the ECG while the T-wave parameters were calculated. The information on the P-wave and QRS complex is not used to access the T-wave parameters, reducing the interference in the MTWA. This was evidenced by the average coherence between the reference and TSC spectra, which was 0.52 ± 0.35. This indicates that the TSC approach may calculate MTWA parameters with minimal interference compared to CA, as evidenced by the high coherence.

Furthermore, the TSC method demonstrated that its alternans frequency amplitude closely approximates the reference amplitude, outperforming the CA method, with

statistical significance ($p > 0.05$). Notably, 43% of cases using the TSC approach achieved a coherence value above 0.5, suggesting that TSC may overcome the limitations associated with CA in MTWA analyses.

In conclusion, our findings support the feasibility of the time-space cancelation method reproduces the MTWA frequency in most baseline drifting scenarios tested. It indicates a lower susceptibility to interferences introduced by baseline corrections when compared to CA. Thus, it has the potential to be used in MTWA analyses. Further studies are necessary to confirm its efficacy in clinical cases.

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