Single Reference Segmentation to Estimate T-Wave Alternans

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Abstract

T-Wave Alternans (TWA) are an indicator of sudden cardiac death risk, and they measure the differences between consecutive T-waves in Electrocardiogram (ECG) studies. In this work, we used ECG Imaging (ECGI) data to scrutinize the spatial distribution of alternans along the torso and epicardium. ECGI signals were obtained from the torso of eight patients suffering from Long QT syndrome and from three control subjects, and epicardial signals were estimated through the inverse problem of ECG. We introduced a new method for segmenting T-waves, called the Single Reference Segmentation (SRS), and we analyzed its performance by estimating TWA and comparing it to the atomic segmentation method, consisting of performing the alignment of each signal in isolation. Our results showed that SRS improves the quality of TWA estimations, which could provide clinically useful representations of the spatial-temporal distribution of TWA using ECGI data.

1. Introduction

Sudden cardiac death (SCD) is a major worldwide problem associated with a high mortality rate in industrialized countries [1, 2]. Therefore, it is necessary to find ways to detect high-risk SCD patients. One of the risk-predictor indices that has been proposed is T-wave alternans (TWA), which measures beat-to-beat changes in amplitude or morphology of the T-wave in an electrocardiogram (ECG). However, it is not a usual procedure in medical practice [2], due to the difficulty of visually assessing TWA since the fluctuations are generally in the order of microvolts in surface ECG. This prevents doctors from analyzing, identifying, or estimating TWA without the use of signal processing and estimation techniques [1].

For TWA analysis, signal processing and estimation techniques are essential. However, there is no consensus on which signal processing and TWA estimation techniques should be used to extract clinically relevant results due to the technical difficulties associated with TWA estimation [2]. For example, ECG signals are known to be affected by different types of noise, some of which overlap the spectral range of physiological data. This represents one of the main problems in automatic TWA detection and estimation because most cases of TWA consist of changes of the order of microvolts in T-wave amplitude or morphology, making it difficult to differentiate noise from T-wave physiological information [3]. Therefore, it is fundamental to continue developing new robust approaches and taking advantage of available tools to reach the desired consensus.

One of these new approaches can be the use of ECG Imaging (ECGI) data to assess TWA spatially and temporally [4, 5]. Our work intends to propose a new signal processing method to improve the analysis of TWA using ECGI data in both epicardium and torso. Pre-processing steps are first applied to each epicardium and torso signal, and TWA are then estimated using the temporal method. M-Mode representations are used to verify the elimination of noise, the conservation of physiological information, and the spatial-temporal consistency of the beats.

The work is organized as follows. The pre-processing and processing steps are explained in Section 2, with special emphasis on the newly proposed T-wave segmentation method. Experiments performed and results obtained in control subjects and in cardiac patients are described in Section 3. Finally, the conclusions are presented in Section 4.

2. Signal Processing

The same pre-processing steps were applied to all epicardium and torso signals. Firstly, a baseline wander (BW) detrending was done, using a spline interpolator, to remove low-frequency noise. Then, a low pass filter with zero-phase distortion was used to eliminate high-frequency noise. To ensure that no physiological information was filtered out, the signals were analyzed both before and after applying the filters.

To correctly estimate TWA, it is essential to properly

segment the T-waves. In this work, a new approach for T-waves segmentation is proposed, called the Single Reference Segmentation (SRS) method, and it is compared to a commonly used method, called the Atomic Segmentation (AS) method. AS involves detecting R-waves and subsequently identifying T-waves based on the location of R-waves. Subsequent T-wave alignment is necessary, but problems can arise in cases where R-waves are not correctly detected, which may occur under diseased conditions. Therefore, new processing techniques are required to allow for robust segmentation of T-waves.

Our SRS T-wave segmentation procedure works as follows. First, all the R-waves are correctly detected at a single spatial point. For that signal, one complete beat is manually segmented, starting at t_1 and ending at t_2 (relative times in this beat). Second, the signal segments from t_1 to t_2 are displayed for every mesh point in the same plot, so that T-waves can be manually and immediately segmented to the segment going from t_{on} to t_{off}, representing the T-wave onset and offset, respectively. Third, time intervals between the R-wave of the segmented beat and t_{on} and between the same R-wave and t_{off} are measured and used to locate the time points where each T-wave starts and ends in the signal in which R-waves are properly detected. Once all the T-waves are localized in one signal, their starting and ending positions are used to detect T-waves in the rest of the mesh points. This T-wave segmentation is robust on the R-wave segmentation, and it can achieve better results by exploiting the synchronous activity in all mesh points.

After the T-wave segmentation step, even and odd templates for each mesh point are generated by averaging its even and odd waves, respectively. For comparison purposes, the mean of even (odd) templates in all mesh points is subtracted to all even (odd) templates, which are also normalized. Finally, the corresponding even and odd templates are subtracted to estimate TWA for each mesh point.

3. Experiments and Results

The ECGI database used contains recordings from eight patients with Long QT Syndrome (LQTS) and three control subjects. The data were acquired at the Cardiac Bioelectricity and Arrhythmia Center, Yoram Rudy Lab at Washington University in St. Louis, from a previous study [6]. Torso measurements were extracted from body surface potential mapping, and epicardial potentials were estimated by solving the inverse problem of electrocardiography and using other imaging modalities [4].

Figure 1 shows how pre-processing steps have affected the signals. Both epicardium and torso in control and LQTS subjects signals seem almost free of noise, and BW noise is not present either. Similar behavior is observed in the signals of most other patients.

Figure 2 shows T-waves segmented using AS and SRS

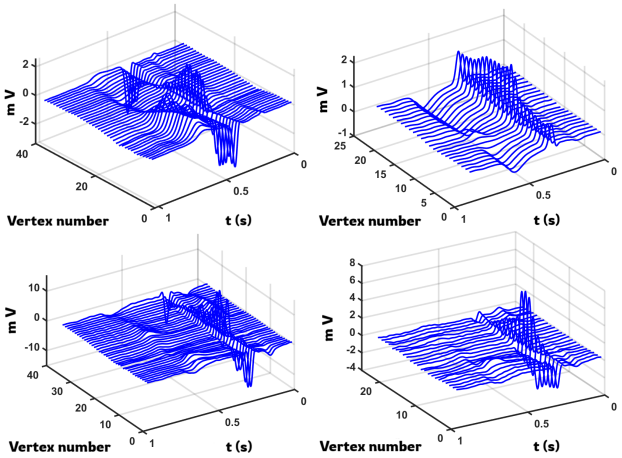

Figure 1. First beat comparison between control and LQTS epicardium and torso meshes. Up: First beat in control 2 epicardium (left) and torso (right). Down: First beat in LQTS 7 epicardium (left) and torso (right).

methods, for a control subject and for a LQTS patient. In both of them, the differences between even and odd waves are markedly lower when using the second method. Note that the vertical scales are different for each method.

Figure 3 shows the spatial-temporal distribution of TWA, estimated by AS and SRS methods. In the mesh images of Fig. 3, the color scale ranges from red, indicating no TWA presence, to purple, corresponding to 0.03 mV of TWA in the epicardium and 0.06 mV of TWA in the torso. It can be seen that in both control subjects and LQTS patients, the results obtained with SRS are more stable and coherent, as SRS tends to regionalize TWA better than AS. In general, control subjects show more coordinated variations than LQTS patients. Note that the scale changes with the method used in M-Mode plots.

4. Conclusions

This work addressed the estimation of TWA in ECGI recordings by presenting a new T-wave segmentation method that outperforms previous approaches. It has been previously noted that special care is required when denoising ECG signals because TWA are caused by small changes in the order of microvolts between consecutive T-waves, which can be mistaken for noise. However, it has been verified that applying the filters does not remove any physiological information, BW noise has been significantly reduced, and signals appear to be clean in both control and LQTS subjects.

Regarding T-wave segmentation, SRS provides results with increased spatial consistency in both the epicardium and torso compared to the AS method. Our results suggest that assuming synchronous activity among all points

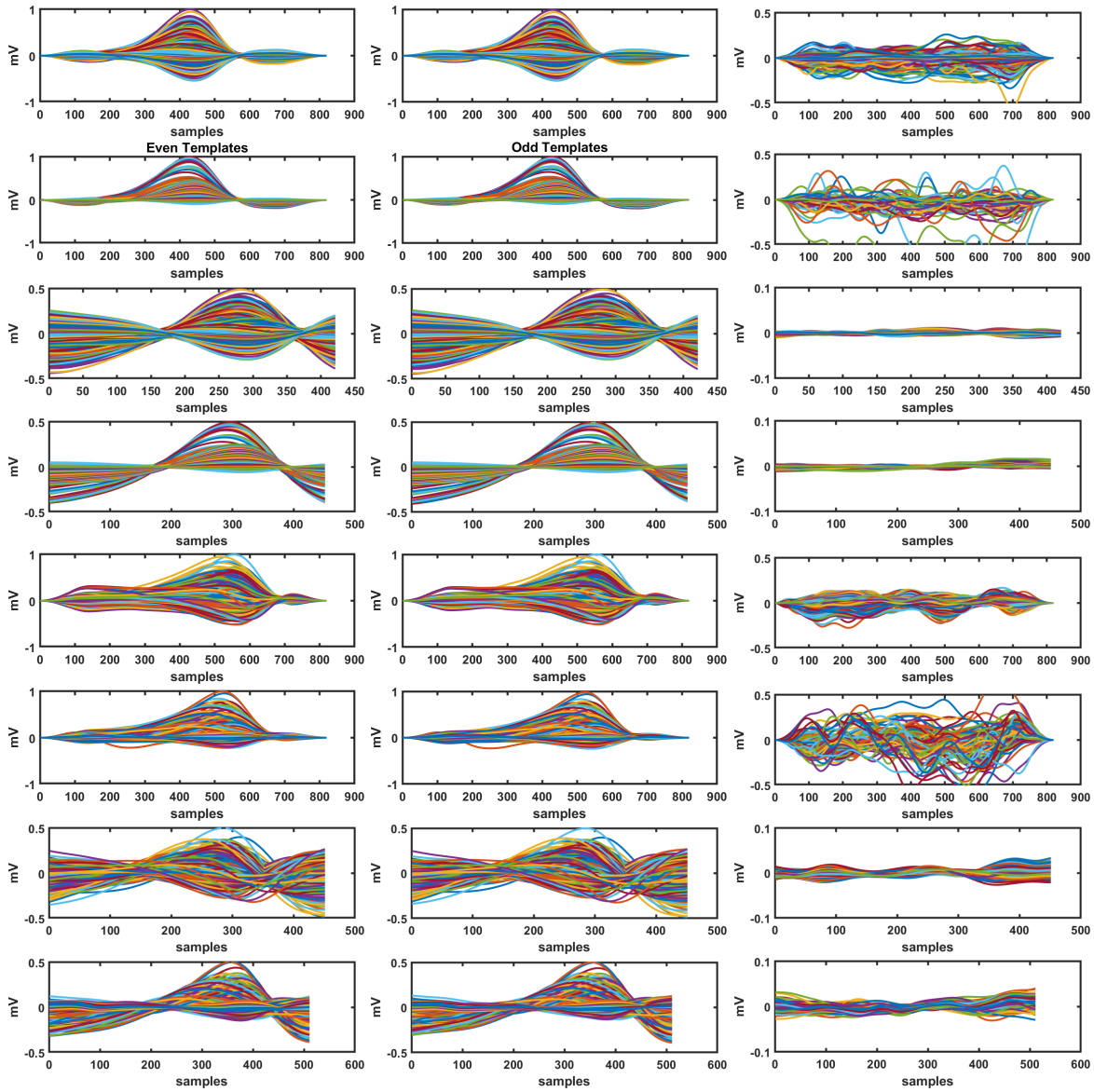

Figure 2. Even and odd T-waves in the epicardium (odd rows) and torso (even rows) of control 16 (rows 1-4) and LQTS patient 8 (rows 5-8), segmented using AS (rows 1,2, 5, 6) and SRS (rows 3,4, 7, 8), comparing even (left) and odd (middle) T waves segmented with each method, and the difference between them (right). See text for detailed discussion.

belonging to the same mesh solves many of the preprocessing and estimation problems that arose previously. In this context, a new avenue of research for exploring alternans opens up. Further studies will be performed to determine the areas where TWA are present with certainty.

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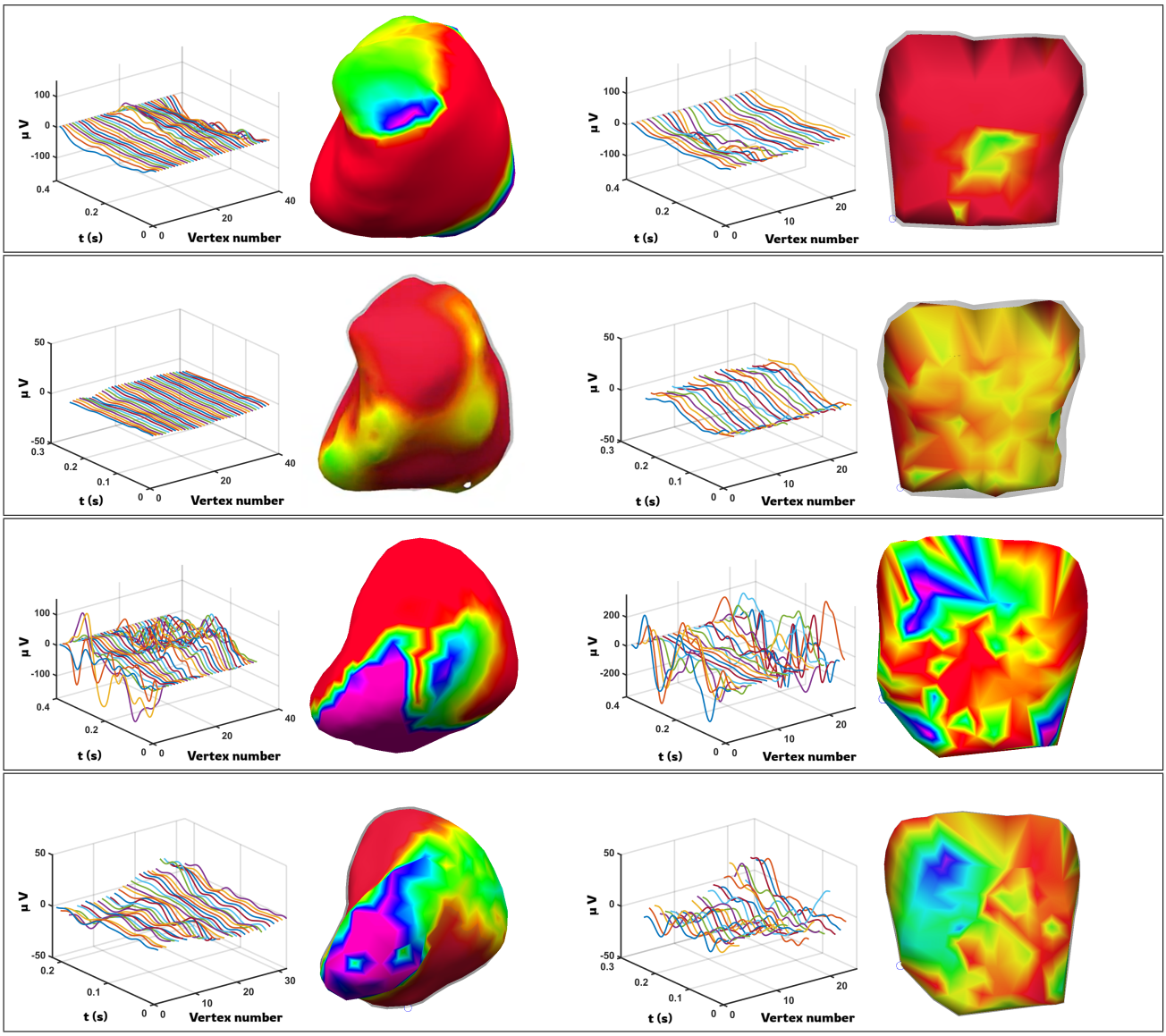

Figure 3. TWA estimated by AS and SRS in a control subject and a LQTS patient epicardium and torso meshes. The first two upper boxes represent TWA estimated with AS (up) and SRS (down) in control 2 epicardium (left) and torso (rigth). The other two boxes show TWA estimated with AS (up) and SRS (down) in the epicardium (left) and torso (rigth) of LQTS patients 8 (M-Mode plots) and 9 (mesh plots).

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