An Innovative Approach to ECG Ventricular Activity Suppression in Persistent Supraventricular Tachycardia

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Abstract

Supraventricular tachycardia (SVT) is a common arrhythmia affecting the heart upper chambers, causing symptoms like palpitations and dizziness, and potentially leading to clot formation. Diagnosis involves an ECG to visualize the P-wave, which is straightforward in sinus rhythm but challenging during tachycardia due to QRS-T waves masking the P-wave. Unmasking the P-wave typically requires signal analysis to cancel out the QRS-T waves. The dataset, collected from Hospital Clínico Universitario Virgen de la Arrixaca Arrhythmia Unit, includes six SVT studies and all their related and recorded signals. These records cover various SVT types, such as orthodromic tachycardias or intranodal tachycardia. Our method involves creating a high-quality template from the sinus rhythm, which is then subtracted from the tachycardia signal to extract the P-wave. Our experiments focused on canceling the QRS complex, with or without the T-wave. The outcome was checked to represent an improvement in visual detection in 66.7% of the cases. The algorithm developed cancels the QRS-T waves, considering the corrected QT value and aiding accurate diagnosis.

1. Introduction

Supraventricular tachycardia (SVT) is a common family of arrhythmias originating in the atria or atrioventricular (AV) node. It is characterized by increased heart rate from 60-70 bpm to 200-300 bpm. It is estimated that SVT has a prevalence of 2.25 per thousand and an incidence of 35 per hundred thousand people per year [1]. The most common symptoms of this family of arrhythmias include rapid or very fast heartbeats, fluttering or strong palpitations in the chest, weakness, chest pain, shortness of breath, fainting or dizziness, and sweating, among others.

SVT can be classified into two main groups, namely, orthodromic tachycardias and intranodal tachycardias. Orthodromic tachycardias occur when an electrical impulse travels in the usual direction through the AV node and then returns via an accessory pathway, creating a re-entry circuit. One of the most common arrhythmias of this type is Wolff-Parkinson-White syndrome. Orthodromic tachycardias result in regular, narrow complex tachycardias with heart rates typically ranging from 200 to 300 bpm, where the P-wave is outside the QRS complex. Intranodal tachycardias, which are the most common type of SVT, occur due to a re-entry circuit within or near the atrial-ventricular (AV) node, involving a slow pathway and a fast pathway. This re-entry mechanism causes a rapid, regular heart rate that can exceed 200 bpm [2]. One of the most common arrhythmias of this type is AV nodal reentrant tachycardia.

P-wave segmentation is challenging due to several factors, including its low amplitude compared to other waves present in the ECG, the variability of its shape and position, and its frequent overlap with the QRS-T complex. Additionally, the P-wave exhibits a similar frequency content to other components, making Fourier analysis unreliable [3]. In recent years, several research groups have proposed methods for P-wave segmentation. Among the most relevant ones are the correlation-based method [4, 5], the template-based method [6], and deep learning approaches using supervised learning [7]. Although P-wave segmentation is a field with several techniques, the number of proposals focusing on detecting P waves in pathological cardiac rhythms is low. Notable contributions include [3], which proposed the use of probabilistic rules, and [8, 9], which applied deep learning algorithms to P-wave detection in intracavitary electrograms.

This study introduces a novel algorithm that cancels QRS-T waves by considering the corrected QT (QTc) value, which is crucial for accurate P-wave diagnosis. Using QRS template methods, we extract, filter, and process waves from the sinus rhythm to create a high-quality template, which is then subtracted from the tachycardia signal to extract the P-wave.

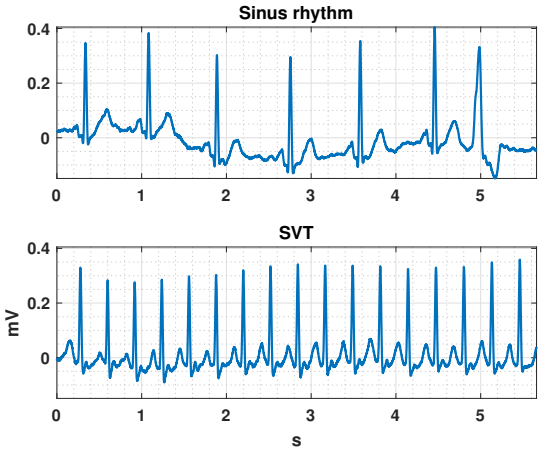

Figure 1: Example of dataset recordings for one patient. Top Panel represents a sinus rhythm signal from I lead, and Bottom Panel represents an SVT signal from the same lead.

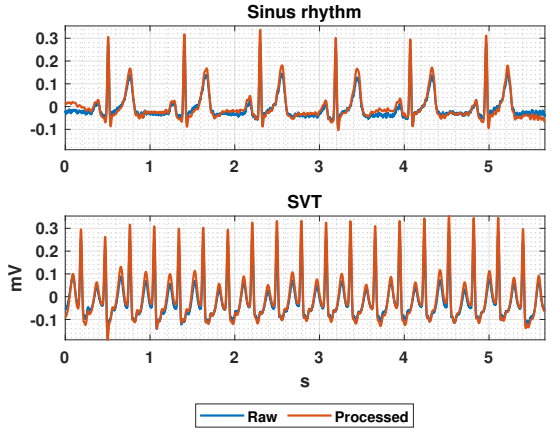

Figure 2: Filtering process example for one patient. Top Panel represents a sinus rhythm signal from I lead, bottom Panel represents an SVT signal from the same lead. The blue signal represents the raw ECG, and the red one represents the signal after the preprocessing stage

2. Materials and Methods

The dataset used in this study was collected and labeled by expert clinicians at Hospital Clínico Universitario Virgen de la Arrixaca, Spain. It consists of data from 6 SVT patients. For each patient, we have two different recordings, a 12-lead ECG in sinus rhythm and a 12-lead ECG of an SVT episode, both with a duration of 5.71±0.13 seconds. These recordings are digitized at 1 kHz with a -2.44 μV resolution. Figure 1 shows an example of these records.

The proposed algorithm consists of three main parts: the preprocessing stage, where the signal is filtered to reduce noise influence in subsequent steps; the subtraction template design, where a high-quality template is created based on the selected waves; and finally, the P-wave isolation, where the previously created template and QTc values are used for correction to isolate the P-wave.

At the beginning of the preprocessing stage, the sinus rhythm signal x_s and SVT signal x_t are filtered using a 32nd-order Butterworth band-pass filter with cutoff frequencies of 1 and 50 Hz. Then, both signals are detrended using cubic splines, with knots selected based on an RR interval approximation for both types of rhythms. Figure 2 shows an example of this processing. After this process, the noise-reduced signals are called x_{cs} and x_{ct}, respectively, and they are given by:

$$x_{cs} = BW(\phi(x_s)) \quad (1)$$
$$x_{ct} = BW(\phi(x_t)) \quad (2)$$

where $BW(\cdot)$ is the baseline detrend algorithm and $\phi(\cdot)$ is the Butterworth band pass filter.

In the subtraction template design stage, we manually selected the QRS onset *QRSon* and the T wave offset *Toff* from one beat from x_{cs}. This QRS-T complex is called the proto-template and is represented as $\hat{y}_{cs}$. Then, we search for R-peaks using a simple QRS detector based on an exponential rule. After that, we align $\hat{y}_{cs}$ with an R-peak aligned segment of $x_{cs}(t)$ and compute the Pearson correlation coefficient between both segments. Finally, we compute the QRST complex template (y_{cs}) as the median of those segments that present a correlation greater than 0.8.

In the last stage, we computed the RR interval by applying the same detector as in the previous step and approximated the QT duration by computing the Framingham QTc [10], which improves the identification of subjects at high risk for malignant arrhythmias or sudden death, and the RR interval computed during sinus rhythm. Then, we correct the duration of our template, denoted as y_{cs}, using spline interpolation, as $\tilde{y}_{cs}$. Finally, we correct the amplitude by minimizing the absolute error beat by beat and subtract the tachycardia beat optimized template from each beat to obtain the QRST-complex-free signal, denoted as z_t, this is,

$$QTc_s = (Toff_s - QRSon_s) + 0.154(1 - RR_s) \quad (3)$$
$$dQRST_t = QTc_s - 0.154(1 - RR_t) \quad (4)$$
$$\tilde{y}_{cs} = \theta(y_{cs}, dQRST) \quad (5)$$

where subindex s stands for sinus rhythm, sub-index t stands for SVT, $dQRST$ is an approximation to QRST complex duration in SVT, and $\theta(\cdot, t_1)$ represents the spline interpolation operator from input duration to t_1.

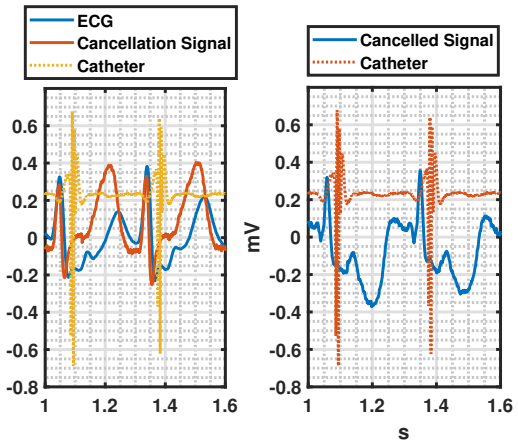

Figure 3: Example of the algorithm first version in which the whole template amplitude and T-wave positioning were erroneous. The left Panel shows the SVT signal, labeled as ECG, the template signal, labeled as cancellation signal, and the signal from a catheter placed in the coronary sinus to confirm the real position of the P-wave visually. The right Panel shows the residual signal between the SVT and template, labeled as canceled signal, and the same catheter as in the left Panel.

3. Experiments and Results

The experiment section is divided into three main parts: testing the validity of the Framingham QTc equation to infer the tachycardia QT duration, testing the validity of different methods to obtain the signal amplitude, and finally, testing the proposed algorithm over all databases and validating it by an expert clinician.

In the first experiment, we aimed to validate the suitability of the QT duration by applying the Framingham QTc equation. Initially, we hypothesized that the correction by itself would be sufficient to approximate the QT duration in SVT. However, this was incorrect, as shown in Figure 3. As can be observed, there is a significant difference in the position of T waves, represented in Panel 1, which causes the canceled signal to not correctly show the P-wave position.

According to these results, we had to modify our algorithm to infer the QT duration in SVT automatically. This modification defined a range of possible QT durations from 3/4 of the QT obtained from the Framingham equation to the QT value in sinus rhythm. These results can be seen in Figure 4, where it is observed that the QRS and T waves are correctly positioned, as shown in Panel 1. However, the wave amplitudes do not correspond with the SVT signal, generating errors that mask the presence of P waves, as seen in Panel 2.

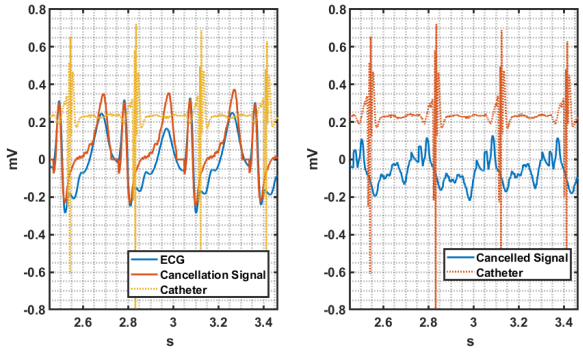

Figure 4: Example of the algorithm second version in which the whole template amplitude was erroneous. The left Panel shows the SVT signal, labeled as ECG, the template signal, labeled as cancellation signal, and the signal from a catheter placed in the coronary sinus to confirm the real position of the P-wave visually. The right Panel shows the residual signal between the SVT and template, labeled as canceled signal, and the same catheter as in the left panel.

In the second part of this section, we aimed to enhance the performance of our proposal to address these amplitude problems. To achieve this, we included a correction using cubic splines, with knots based on the propagation of fiducial points marked on the sinus rhythm template. This propagation considers that the time difference between the fiducial points and the R-wave is maintained throughout the signal. To address the shortening of the QT during SVT, the fiducial points of the T-wave are interpolated to translate their position. Figure 5 shows an example of this processing. In Panel 1, the alignment between the SVT and cancellation signals is almost perfect. On the other hand, Panel 2 shows the difference between the two previous signals, where a spike clearly defines the P-wave position.

Finally, an expert clinician detected the P-waves based on the SVT signal and the output of our proposal. According to his experience, he could identify the P-wave positions in 4 out of the 6 cases in our dataset. In other words, our proposal enhances the visual perception of P-waves in 66.7% of cases.

4. Conclusions

In this work, we have proposed an innovative method for unmasking the P wave during SVT episodes. The basic conceptual stages, consisting of creating a template during Sinus Rhythm and then subtracting it from SVT, need to be aligned and corrected, otherwise the P-wave detector is low. Manual intervention could be readily automatized. The results have shown that quality recovery of the P wave in these conditions is possible, and this represents a useful

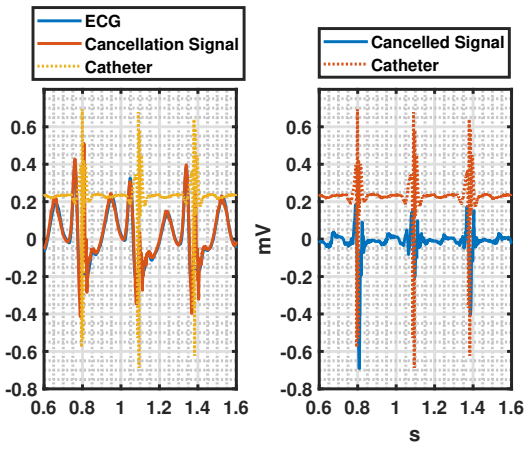

Figure 5: Example of the algorithm final version. The left Panel shows the SVT signal, labeled as ECG, the template signal, labeled as cancellation signal, and the signal from a catheter placed in the coronary sinus to confirm the real position of the P-wave visually. The right Panel shows the residual signal between the SVT and template, labeled as canceled signal, and the same catheter as in the left panel.

electrocardiographic analysis tool in the direction of clinical practice. Future work will be devoted to completing the data, adapting it into a robust algorithm with all the steps automated, creating a processing library that can be used in current ECG polygraph and recorder systems, and validating in a wider practical environment.

Acknowledgments

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