Determination of Atrial Fibrillation Frequency Using QRST-Cancellation with QRS-Scaling in Standard Electrocardiogram Leads

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Abstract

Introduction: Non-invasive assessment of the atrial cycle length can be obtained through QRST-cancellation algorithms. The main spectral component of the QRST-cancelled ECG gives an indication of the atrial cycle length. Due to QRS amplitude variations (eg caused by respiration) small residuals of QRS complexes can remain in the final ECG. We applied a QRST scaling algorithm to minimize these effects. Methods: Standard 12-lead ECG was recorded, simultaneous with both left (LA) and right (RA) intracardiac atrial electrograms. We applied a QRST-cancellation algorithm with automatic QRS-amplitude correction on both atrial fibrillation signals and atrial flutter signals. Results: On average over all leads the percentual deviation between the intracardiac right atrial dominant frequency and the frequency measured on the standard ECG leads was 1.04% for atrial flutter and 2.16% for atrial fibrillation. For comparison with the LA fibrillation frequency, errors were slightly higher (flutter: 3.05%, fibrillation 2.31%). Conclusion: The QRST-cancellation algorithm with automatic QRS amplitude adjustment performs accurate on both atrial fibrillation signals and atrial flutter signals. These methods can have substantial clinical importance in monitoring non-invasively the atrial cycle length after interventional procedures or medication administration.

1. Introduction

Atrial fibrillation (AF) is the most common arrhythmia seen in clinical practice. Its incidence increases with age and it is responsible for considerable morbidity and medical costs [1].

The diagnosis of AF is usually based on an irregular pulse and thus identified in terms of its ventricular consequences rather than in its own right. On the ECG, AF is confirmed by the replacement of the P-wave by rapid fibrillation waves, often of varying frequency and amplitude.

To study the mechanisms of AF mainly invasive recording techniques (e.g. endocardial or epicardial mapping) are used both in animal experiments and in humans because they provide a detailed view of the local electrical activity [2,3]. These techniques have provided insights in the mechanisms initiating and sustaining AF. The degree of organization and wavelength of AF has been found to correlate with the amount of remodelling of the atrial substrate [4,5]. Moreover rapid atrial rates shorten the refractory period and hence the wavelength of AF. Different types of AF have been identified based on the degree of organization and properties of the atrial electrical wave fronts [6].

From a clinical point of view it would be desirable to have non-invasive tools for classification of AF. Therefore focus has turned to the standard 12-lead ECG. Spectral analysis of the ECG can quantify the atrial fibrillation frequency and thus the atrial cycle length. This measure may serve as an index of the degree of atrial organisation and may correlate with atrial refractoriness.

Estimation of the atrial cycle length using the standard ECG requires the elimination of ventricular activity. Therefore the subtraction of the QRS-complex and the T wave should first be established [7,8]. The QRS-complex represents the ventricular depolarisation, the T-wave the ventricular repolarisation. The technique of QRST-cancellation subtracts an averaged QRST-complex from each individual beat. The remaining signal contains only the atrial activity. Spectral analysis of this signal results in one dominant peak, representing a dominant atrial fibrillation frequency.

Due to respiration there is a slight variation in QRS-complex amplitude over time. After subtraction of the averaged QRST-complex residuals of the QRS-complexes can remain in the signal, disturbing the correct quantification of the atrial fibrillation frequency. Therefore, we opted to scale the averaged QRST-complex according to the amplitude of the QRS-complex of each individual beat.

In this study we set out to determine the accuracy of the QRST-cancellation method with QRST scaling by comparing the detected frequency to the dominant frequency measured in the right atrium and the left atrium. We also wanted to determine if there was an ECG lead which would be best to determine the atrial fibrillation frequency using QRST-cancellation. Last we wanted to determine if it was possible to detect the differences in right and left atrial fibrillation frequency using different ECG leads.

2. Methods

In 4 patients with atrial fibrillation and 5 patients with atrial flutter 12-lead ECG was recorded, simultaneous with an intracardiac recording of the electrical activity in the right atrium (RA) and the left atrium (LA) for 10 seconds. For this a catheter tip was placed at the right atrial appendix (RAA) and in the coronary sinus to assess the LA. All channels were digitized at a sample rate of 1000 Hz.

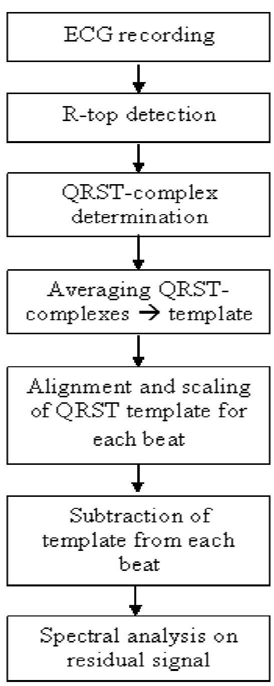

Figure 1. Schematic of the different processing steps for QRST-cancellation.

For QRST-cancellation the ECG is preprocessed in terms of baseline drift removal. For this a highpass filter with cutoff frequency = 0.6 Hz was used (Butterworth, order 6). Each beat was detected by identification of the R top of the QRS complex. This algorithm is described in more detail in [9]. The QRST sequence is determined for all beats in the 10 seconds recording and averaged. This results in a QRST-template. The template is then aligned over each beat and its amplitude adjusted to achieve the best cancellation of the beat. After subtraction of the template at each beat the signal contains predominantly atrial activity. Since the spectral content of interest is well below 20 Hz, the signal is downsampled from 1000 Hz to 50 Hz. Spectral analysis is performed on the residual ECG signal using a Fast Fourier Transform. The spectrum is bandpass filtered between 3 and 12 Hz. The overall AF frequency is determined by the maximum spectral component in the spectrogram. For the RA and LA electrogram the dominant frequency was detemined by the maximum of the power spectrum of the whole signal. The algorithm was implemented in LabVIEW version 7.1 (National Instruments, Austin, Tx, USA).

3. Results

The mean atrial cycle length detected during atrial fibrillation was 233 ± 14 ms (~5.5 Hz). During atrial flutter the mean atrial cycle length was 331 ± 25 ms (~3.9 Hz). For atrial fibrillation the difference between the RA and LA cycle length was 6 ± 6 ms (range 1-12 ms). In atrial flutter this difference was 7 ± 8 ms (range 1-18 ms).

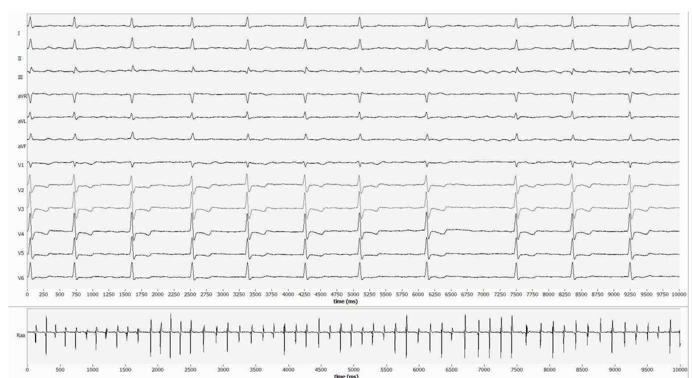

Figure 2: Example of the 12 lead ECG during atrial fibrillation. The lower tracing illustrates the electrogram recorded in the right atrium.

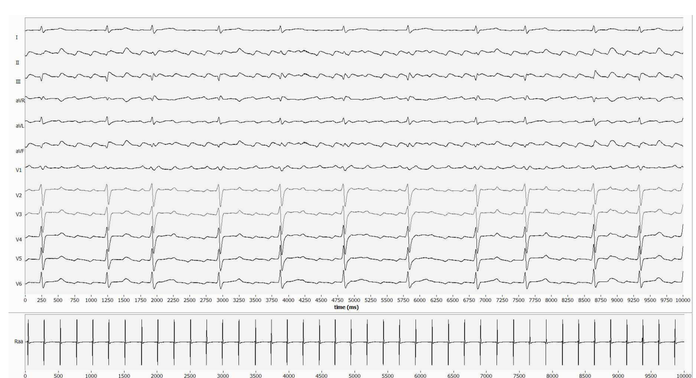

Figure 3: Example of the 12 lead ECG during atrial flutter. The lower tracing illustrates the electrogram recorded in the right atrium.

Figures 2 and 3 show examples of the 12 lead ECG and the right atrial lead during atrial fibrillation and atrial flutter. Figures 4 and 5 show the result of the FFT after QRST-cancellation. The main peak denotes the atrial flutter/fibrillation frequency.

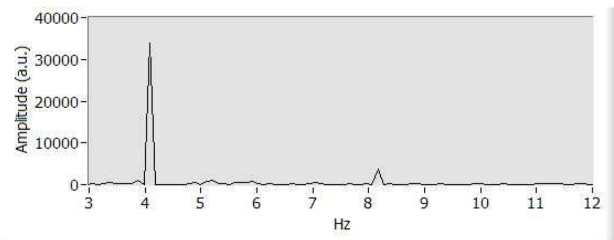

Figure 4: Result of QRST cancellation during atrial flutter.

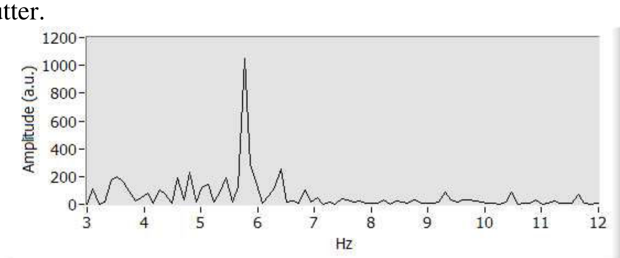

Figure 5: Result of QRST-cancellation during atrial fibrillation.

For atrial flutter signals the best matches with the right atrial lead were obtained in lead V2. This lead produced the smallest deviation from the real atrial frequency. The maximum error was found in lead V6. The same leads were found to give the best/worst results when using the left atrial signal as a reference. In general the frequencies derived from the standard ECG leads had higher errors when compared to the left atrial leads. Mean error compared to RA electrogram over all leads was 1.04%, compared to 3.05% for the left atrial lead.

Error (%) from frequency measured in right atrium				
	Mean	SD	Minimum	Maximum
I	1.51	1.98	0.02	4.99
II	0.98	0.71	0.19	1.90
III	1.23	1.18	0.05	2.98
AVR	0.93	0.91	0.05	1.94
AVL	1.26	1.38	0.05	2.98
AVF	0.98	0.86	0.27	2.41
V1	0.75	0.74	0.05	1.76
V2	0.21	0.14	0.05	0.32
V3	0.67	0.43	0.19	1.20
V4	0.69	0.94	0.05	2.30
V5	1.47	2.09	0.05	4.90
V6	1.83	2.03	0.07	5.23

Table 1: Error (%) for atrial flutter compared to RA electrogram.

Error (%) from frequency measured in right atrium				
	Mean	SD	Minimum	Maximum
I	1.65	0.78	0.83	2.62
II	2.53	2.22	0.33	5.50
III	2.24	2.46	0.38	5.86
AVR	1.48	1.55	0.10	2.86
AVL	2.08	2.46	0.17	5.60
AVF	1.97	2.24	0.10	4.77
V1	2.34	4.06	0.10	8.41
V2	3.60	4.03	0.25	8.74
V3	2.17	1.35	0.25	3.37
V4	1.56	1.15	0.33	2.62
V5	2.60	2.49	0.33	5.67
V6	1.69	1.11	0.33	3.01

Table 2: Error (%) for atrial fibrillation compared to RA electrogram.

Error (%) from frequency measured in left atrium				
	Mean	SD	Minimum	Maximum
I	3.39	2.21	0.60	6.32
II	3.27	3.07	0.62	7.29
III	3.43	2.86	0.86	7.09
AVR	3.14	2.89	0.49	7.29
AVL	3.45	3.23	0.71	7.86
AVF	2.89	3.08	0.27	7.78
V1	2.90	2.80	0.49	7.16
V2	1.11	0.99	0.27	2.21
V3	2.81	2.49	0.27	6.37
V4	2.90	2.98	0.27	7.68
V5	3.64	4.06	0.27	10.13
V6	3.70	2.52	0.49	6.96

Table 3: Error (%) for atrial flutter compared to LA electrogram.

Error (%) from frequency measured in left atrium				
	Mean	SD	Minimum	Maximum
I	2.15	1.18	0.83	3.20
II	2.10	1.33	1.30	4.08
III	2.36	1.42	0.96	4.13
AVR	1.80	1.65	0.17	4.08
AVL	1.73	1.66	0.17	3.87
AVF	1.65	1.74	0.21	4.08
V1	3.81	4.09	0.25	9.63
V2	3.05	4.62	0.25	9.95
V3	2.68	2.25	0.25	5.26
V4	1.89	1.29	0.83	3.76
V5	2.16	1.82	0.83	4.86
V6	2.37	1.33	1.50	4.31

Table 4: Error (%) for atrial fibrillation compared to LA electrogram.

For atrial fibrillation signals the best match with the RA electrogram was found in lead aVr. Lead V2 produced the largest deviation from the frequency detected in RA. Compared to the left atrial frequency, lead aVf was the closest match (error 1.65%). Lead V1 produced the largest deviation (error 3.81%).

Mean error compared to the RAA fibrillation frequency over all leads was 2.16% while for the left atrial fibrillation frequency the error was 2.31% over all leads.

4. Discussion and conclusions

The method of QRST-cancellation was able to determine the atrial fibrillation period both during atrial fibrillation and atrial flutter.

For the atrial flutter signals the best lead was V2, producing the smallest errors.

Our results indicate that with standard leads the method of QRST-cancellation works accurately. The most critical step in the QRST-cancellation remains the correct determination of the QRST template.

The errors during atrial fibrillation with the RA electrogram are slightly higher compared to atrial flutter. This can be explained by the more irregular nature of atrial fibrillation. Due to the multiple waves travelling through the atrium several frequencies can occur at the same time. Even during a 10-second recording the atrial fibrillation frequency can change during the recording.

During atrial flutter there is typically one wavefront that moves continuously over the atrium producing a more stable fibrillation frequency.

This method can have potential applications in non-invasively monitoring the atrial fibrillation rate using holter recordings. It can also have an application in combination with joint time-frequency techniques for directly monitoring the influence of drugs administration influencing the atrial refractory period or in helping the predictive evaluation of patients.

In general the errors in detecting the atrial fibrillation frequency and atrial flutter frequency remained very small. The differences between the various ECG-leads were negligible. All standard leads can be used for QRST-cancellation. Future research will focus on applications of this method with drug administration in combination with joint time-frequency analysis techniques.

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