

The Influence of QRS Cancellation on Signal Characteristics of Atrial Fibrillation in the Surface Electrocardiogram

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Abstract

QRS cancellation methods have been used to analyze atrial activity in the ECG including atrial fibrillation. In this study, the contribution of imperfect cancellation was evaluated by comparing "pure" atrial fibrillation in a brief ventricular asystole after RF ablation of the AV junction, and data obtained by the cancellation method during pacing just before and after. The results were compared by linear regression. The peak frequencies were 4.8-7.3 (5.5 ± 0.8) Hz for the "pure" and 4.8-6.7 (5.4 ± 0.7) Hz for the cancelled ECG segments ($R^2 = 0.89$), and the mean STFT peak frequencies were 4.6-6.9 (5.8 ± 0.7) Hz for the "pure" and 4.8-6.8 (5.8 ± 0.7) Hz for the cancelled segments ($R^2 = 0.97$). Thus, cancellation is reliable for characterizing atrial fibrillation. The peak frequency and most power for atrial fibrillation are in the 4-9 Hz band as reported previously.

1. Introduction

Atrial fibrillation is a common arrhythmia with a prevalence of approximately 0.4-1.0% in the general population. Prevalence increases with age and it is estimated to be present in 5% of those older than age 65, and 10% of those older than 70 [1]. It is associated with an increased risk of stroke and mortality, as well as impaired exercise tolerance, fatigue, and heart failure [1, 2]. There are data to suggest that signal characteristics of atrial fibrillation, derived from the intra-atrial electrogram or the surface ECG, reflect the underlying atrial pathophysiology, and therefore may allow insights that could benefit patient care [3-5].

Frequency domain analysis has been used in the surface ECG to characterize atrial fibrillation, and the basic idea is to cancel the ventricular activity by using template matching or other methods followed by calculating the power spectrum of the remainder ECG [6-8].

Due to imperfect cancellation, the residual QRS complexes and T waves in the remainder ECG as well as any noise in the data may affect the results. Some improvements in cancellation methods have been

reported [9]. However, no matter how good the cancellation is, there remains a concern that the residual ventricular signal or some other information brought in by the cancellation method itself may alter the results. Therefore, we studied "pure" atrial fibrillation obtained by briefly stopping pacing in patients with complete AV block after radiofrequency ablation of the AV junction and compared the results with the adjacent remainder ECG obtained by cancellation of paced beats just before and after the "pure" segment.

2. Methods

2.1. Subjects

Subjects for this study were patients undergoing routine radiofrequency ablation of the AV junction for ventricular rate control of atrial fibrillation. In order to test for the presence of complete heart block and to evaluate the presence of escape rhythms, pacing was briefly discontinued and then restarted. During this procedure, the surface ECG was continuously digitized on a physiologic recording system (Prucka/GE Medical, Inc., Milwaukee, Wisconsin.) The project was reviewed and approved by the Institutional Review Board of Evanston Northwestern Healthcare.

2.2. Data processing

The "pure" atrial fibrillation segments were chosen as starting from after the T wave of the last paced beat, and ending before the first restarted pacing spike. The adjacent surface ECG with paced QRS complexes just before and after the "pure" segments were recorded long enough for QRS cancellation based on the template matching method. All the segments were extracted from the physiologic recording system (sampling rate: 977Hz) and saved on floppy disks. The dc component was eliminated before calculation. A low-pass filter with a cutoff frequency of 50Hz and a high-pass filter with a cutoff frequency of 1Hz were applied.

2.3. Power spectrum analysis

Lead V1 has the highest ratio of atrial fibrillation signal amplitude to QRS amplitude; therefore it was chosen for the analysis. The peak frequency, median frequency (defined as the frequency dividing the 4-9 Hz region power in half), percent power in 4-9 Hz band (defined as the ratio of power in the 4-9 Hz region to the total power in the power spectrum) [8], and mean short-time Fourier transform (STFT) peak frequency (mean of peak frequency in each STFT window) were also calculated.

1) "Pure" atrial fibrillation signal

For the "pure" atrial fibrillation segments, zeros were padded at both ends of the signals to increase frequency resolution before a discrete Fourier transform was performed to obtain the power spectrum. For this study, the frequency resolution was kept <0.1 Hz.

2) Cancelled paced complexes

For the ECG segments with QRS complexes, the first step was to detect fiducial points and to align all the beats in that segment to generate a median beat. Next this median beat was aligned at each fiducial point and subtracted from the ECG to obtain the remainder ECG (named cancelled ECG). The fiducial point detection method followed the algorithm presented by Pan and Tompkins [10]. Once the subtraction was completed, the power spectra for the cancelled ECGs were calculated in the same way as for the "pure" atrial fibrillation segments.

"Pure" atrial fibrillation signal segments were shorter than the cancelled ECG segments, and the comparison was done after zero padding both the "pure" segment and the cancelled ECG to the same length in order to obtain the same frequency resolution (<0.1 Hz).

For the cancelled paced complexes, the average peak frequency of the remainder ECG segments just before and after the "pure" segment was calculated for comparison

with the peak frequency of the "pure" segment. Values of the average peak frequencies were compared with the peak frequencies of "pure" atrial fibrillation by using linear regression. The median frequency was studied in a similar way.

However, atrial fibrillation lacks stationarity and even several second difference in time may lead to visible changes in the result. In addition, these three segments did not have the same length. In some cases, the power spectrum of the cancelled ECG might contain multiple peaks close in frequency with similar amplitudes, and in some sub-segment, one of the peaks was relatively dominant, so it might not be fair enough to choose one of the peaks with the highest amplitude as the peak frequency. Thus, in order to study the temporal fluctuation of peak frequency, a STFT method was applied. The signal was segmented by a short window (length 1s) and the peak frequency in each window was computed, the mean of which was called the mean STFT peak frequency. This parameter and its standard deviation might characterize atrial fibrillation in a more reasonable way.

3. Results

A total of eleven patients with atrial fibrillation were included in this study. The patients were two males and nine females, ages 49 to 88 yr (72 ± 13 yr). The duration of data segments of "pure" atrial fibrillation ranged from 1.8s to 4.5 s (2.9 ± 1.0 s) and the duration of the segments with QRS complexes just before and after the "pure" segment fell in the range of 4.5-12.0 s (7.5 ± 2.3 s). In addition, two subjects with sinus rhythm at the time of the ablation procedure were also studied as a control.

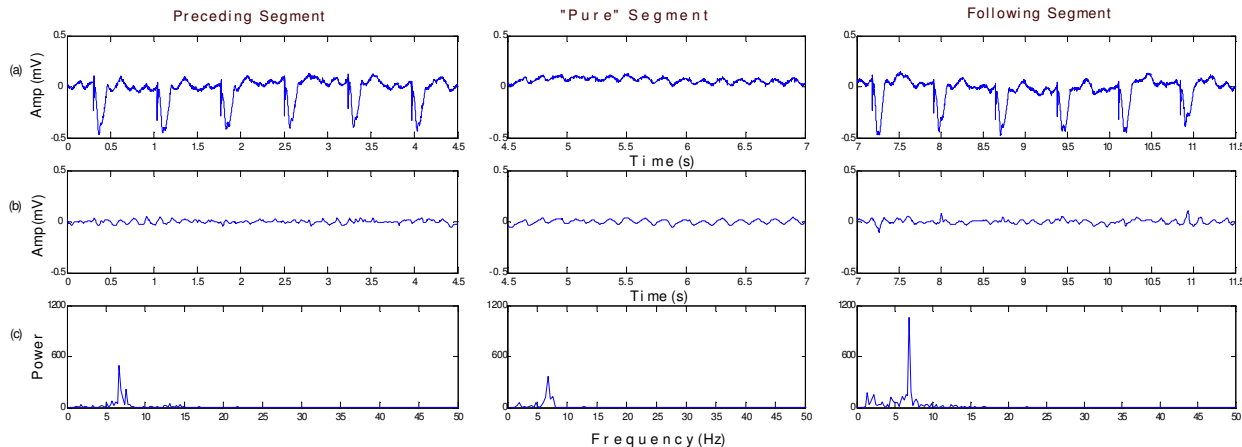


Figure 1. Original ECG segments with paced QRS complexes preceding and following the "pure" segment as well as the "pure" segment itself (a), and the corresponding remainders (for the "pure" segment, the "remainder" shown is the filtered "pure" segment) (b), power spectra of remainders (c), respectively. These three panels represent a continuous recording.

One representative “pure” atrial fibrillation segment and the ECGs (lead V1) with QRS complexes just before and after this “pure” segment, their corresponding remainder ECGs and power spectra of remainders are shown in figure 1. In order to compare all three segments clearly, the “remainder” of the “pure” segment is shown as the filtered “pure” segment itself. The power spectra of the cancelled ECG segments are quite similar to that of the “pure” atrial fibrillation signals. The peak frequency position is quite similar for this patient for these three segments.

The “pure” segment with its power spectrum of a control sample (sinus rhythm) is shown in figure 2. Significant differences can be seen. For each of the examples of sinus rhythm, harmonic peaks are clearly displayed in the frequency domain because of the rhythm’s significant periodicity, and the fundamental peak represents the sinus rate. However, for atrial fibrillation, there are no remarkable harmonics.

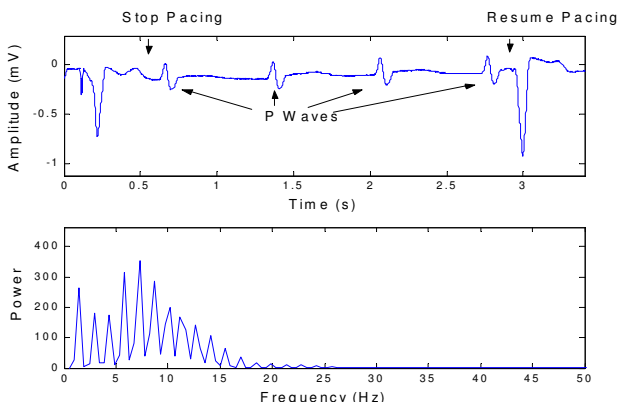
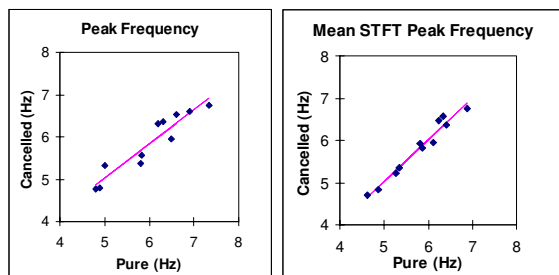


Figure 2. “Pure” atrial activity during sinus rhythm and its power spectrum. A paced QRS complex is shown at either end of signal (but not included in calculation of power spectrum).



(a) (b)

Figure 3. Peak frequency (a) and mean STFT peak frequency (b) comparison of “pure” vs. average of cancelled. Slope of the fitted line is 0.81 (a), 0.99 (b), and the vertical-axis intercept is 0.98 Hz (a), 0.06 Hz (b). R squared is 0.89 (a), 0.97 (b).

In figure 3 (a), a plot of the peak frequencies (in Hz) of lead V1 for all the patients is shown. The horizontal axis represents the peak frequency of the “pure” segment, and the vertical axis represents the average of the peak frequencies of the adjacent cancelled ECG segments. Each patient is shown by a dot, and the line is the fit of linear regression. The data points are strongly correlated. The peak frequencies fall in the range of 4.8-7.3 Hz (5.5 ± 0.8 Hz) for the “pure” segments and 4.8-6.7 Hz (5.4 ± 0.7 Hz) for the cancelled ECGs ($R^2 = 0.89$). To avoid redundancy, a similar result of median frequency is not shown. A similar but better result of mean STFT peak frequency is shown in figure 3 (b). The mean STFT peak frequencies are 4.6-6.9 Hz (5.8 ± 0.7 Hz) for the “pure” segments and 4.8-6.8 Hz (5.8 ± 0.7 Hz) for the cancelled ECGs ($R^2 = 0.97$). Compared to the peak frequency study without short-term data, this gives a close fit.

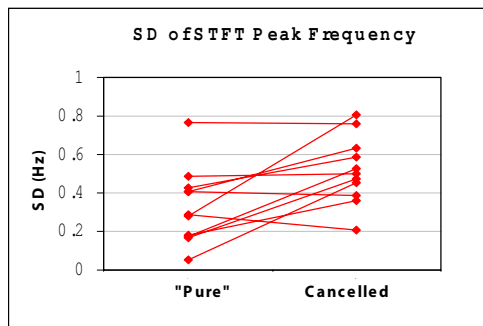


Figure 4. Comparison of the standard deviation of STFT peak frequency for the “pure” and the average of cancelled.

Standard deviation of STFT peak frequency for the “pure” segments and the average of the cancelled ECGs is shown in figure 4. Each patient is shown in pair with the 1st dot representing the “pure” and the 2nd dot representing the average of the cancelled data. For most cases, this standard deviation of cancelled data is larger than that of the “pure”.

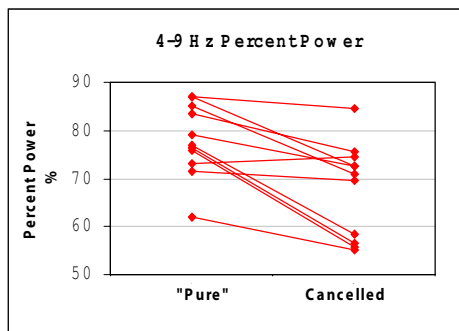


Figure 5. Comparison of percent power in the 4-9 Hz band for the “pure” and the average of cancelled.

Percent power in the 4-9 Hz band for the “pure” segments and the average of the cancelled ECGs are compared in figure 5. For both “pure” segments and cancelled ECGs, this percent power is no less than 55%. For most cases, the “pure” segment has a slightly higher percent power compared to the remainder ECG obtained by cancellation.

4. Discussion

In this study, cancellation of QRS complexes was shown not to change the frequency domain characteristics of atrial fibrillatory signals qualitatively, and was associated with only minor quantitative changes. Therefore, the use of QRS cancellation for the purpose of characterizing atrial signals is validated.

However, minor quantitative differences were found between the “pure” and the cancelled signals, such as difference in the peak frequency, standard deviation of STFT peak frequency, and the percent power in 4-9 Hz. There are at least two potential explanations. First, imperfect cancellation can introduce small errors by leaving uncanceled ventricular signals or over subtracting atrial activities in the remainder ECG. However, atrial fibrillation lacks stationarity, and changes in the atrial fibrillation signal itself over the time scale of a few seconds may have contributed to measured differences between the “pure” segments and the preceding and following cancelled counterparts.

5. Conclusion

Frequency domain features for both “pure” atrial fibrillation signals and adjacent remainder ECGs obtained by the cancellation method were studied, and the results showed strong correlation. Thus the remainder ECG can be used as a reliable representation to characterize atrial activity.

In addition, peak frequency and most power for all the patients for both “pure” and cancelled ECG segments did fall in a range of 4-9 Hz, which was consistent with previous studies of atrial fibrillation.

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References

- [1] Glauser J. Atrial fibrillation. Part I: etiologies and strategies for ventricular rate control. *Geriatric Emergency Medicine Report*. Feb 2001.
- [2] Brand FN, Abott RD, Kannel WB, Wolf PA. Characteristics and prognosis of lone atrial fibrillation: 30-years follow up in the Framingham study. *JAMA* 1985; 254:3449-53.
- [3] Levy S, Breithardt G, et al. Atrial fibrillation: current knowledge and recommendations for management. *European Heart Journal* 1998;19:1294-320.
- [4] Ropella KM, Sahakian AV, Baerman JM, et al. Effects of Procainamide on intra-arterial electrograms during atrial fibrillation-implication for detection algorithms. *Circulation* 1988;77:1047-54.
- [5] Bollmann A, Kanuru NK, McTeague KK, et al. Frequency analysis of human atrial fibrillation using the surface electrocardiogram and its response to ibutilide. *Am J Cardiol* 1998;8:1439-45.
- [6] Slocum J, Sahakian A, Swiryn S. Diagnosis of atrial fibrillation from surface electrocardiograms based on computer-detected atrial activity. *J. Electrocardiol.* 1992;25:1-8.
- [7] Shkurovich S, Sahakian A, Swiryn S. Detection of atrial activity from high-voltage leads of implantable ventricular defibrillators using a cancellation technique. *IEEE Trans. Biomed. Eng* 1998;45:229-34.
- [8] Slocum J, Byrom E, McCarthy L, Sahakian A, Swiryn S. Computer detection of atrioventricular dissociation from the surface electrocardiogram during wide QRS tachycardias. *Circulation* 1985;72:1028-36.
- [9] Stridh M, Sornmo L. Spatiotemporal QRST cancellation techniques for analysis of atrial fibrillation. *IEEE Trans. Biomed. Eng* 2000;48:105-11.
- [10] Pan J, Tompkins WJ. A real-time QRS detection algorithm. *IEEE Trans. Biomed. Eng* 1985;32:230-6.

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