WAVELET ANALYSIS OF ATRIAL FIBRILLATION ELECTROGRAMS

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ABSTRACT

The problem of extracting time resolved beat spacing intervals from atrial fibrillation electrograms using wavelet analysis techniques is considered. The problem has the important application of localizing organized but intermittent sources of AF from complex time-dependent AF electrograms measured with a basket catheter. Analysis of synthesized electrograms demonstrates that beat spacing can be extracted accurately. The technique is then applied to acute and chronic AF electrograms measured from canine models of AF and comparisons of the results are examined.

1. INTRODUCTION

Atrial fibrillation (AF) is the most common cardiac arrhythmia, affecting nearly 1% of the population and up to 5% of the population over 80 years old [1]. AF is associated with an increased risk of stroke (five-fold over sinus rhythm) and mortality, impaired exercise tolerance, fatigue and heart failure. AF is characterized by rapid (>400 beats/minute) irregular electrical excitation of the atrial cardiac tissue leading to inefficient pumping of blood from the atria to the ventricles. While the precise physiological mechanisms of initiation and maintenance of AF remain elusive [2] there is increasing evidence that AF is driven by localized organized sources of electrical activity [2-3]. This knowledge has been put into clinical practice and an important therapeutic intervention of AF is tissue ablation [3-4], where an AF source is destroyed using radiofrequency energy. Success of this therapy depends critically on the ability to locate the source, and therefore significant improvements in AF therapy can be gained by improving the ability to detect a source.

A majority of sources have been shown to be focal sources that originate in the pulmonary veins[4]. Another possible source of AF is called a rotor or a spiral wave, where the wave front propagation forms a closed loop (re-entry) and electrical activation propagates away from the center of rotation to excite the rest of the atrium.

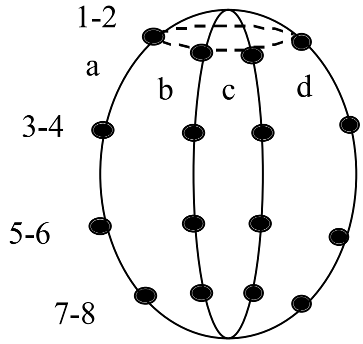

Figure 1: Basket Catheter Electrodes

Reentrant sources have been identified in animal models of excised hearts using a combination of voltage sensitive dyes to visualize the wave behavior and simultaneous electrode recordings at a number of spatial locations[5]. It was also found in the same study (via FFT analysis) that the re-entrant source was highly periodic and had a characteristic frequency far higher than normal sinus rhythm.

One method of clinical testing for detecting localized sources of AF is to insert a basket catheter (figure 1) into the atrium and measure the electrical activity with electrodes at a number of spatial locations (32 locations in the case considered here). The basket splines are labeled a-f and each spline has four bipolar electrodes labeled 1-2, 3-4, etc. In this work, we consider the use of wavelet analysis for improving the ability to detect spatially localized organized AF sources from basket catheter measurements of AF electrograms.

2. AF ELECTROGRAMS

The AF electrograms analyzed in this paper were obtained from a reliable *in vivo* canine model of acute and chronic atrial fibrillation. Acute AF was induced in dogs (n=6) after 48 hrs of rapid atrial pacing. Chronic AF was initiated in additional dogs (n=8) by inducing mitral regurgitation followed by prolonged pacing (>8 weeks). A 64-electrode basket catheter was placed in the left atrium (LA) using a trans-septal approach. Bipolar electrograms were recorded during AF for 60 s. Representative acute and chronic electrograms are presented in figure1 and the individual beats in each signal signify the passage of a cardiac wave front at the location of the electrode. It is clear from these figures that chronic AF is significantly more complex than acute AF.

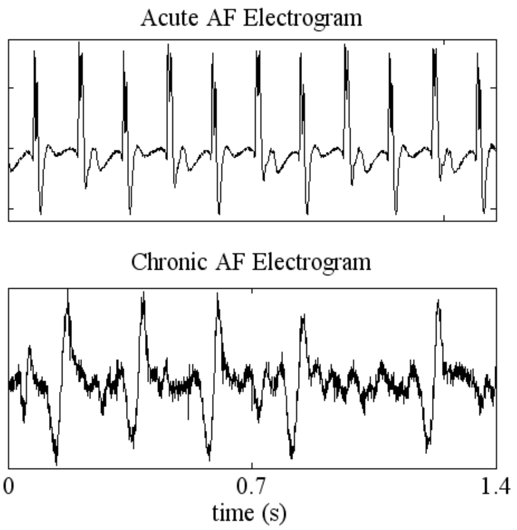

Figure 2: Electrograms from acute and chronic AF.

3. CONTINUOUS WAVELET TRANSFORMS

The continuous wavelet transform is given by

$$W(a,\tau) = a^{-1/2} \int_{-\infty}^{\infty} f(t)\psi^{*}\left(\frac{t-\tau}{a}\right)dt \qquad (1)$$

where a is the scale, τ is a time shift and $\psi(t)$ is the analyzing wavelet. The wavelet transform projects a fluctuation, $f(t)$, onto time-localized wavelet functions which adapt their window size to the frequency range to be examined. This work uses the complex-valued Morlet wavelet,

$$\psi(t) = e^{i5.5t} e^{-t^2/2} \qquad (2)$$

which is a Gaussian-windowed complex sinusoid. The wavelet transform of an AF electrogram is presented in figure 3, where time is on the horizontal axis, scale is on the vertical axis and the intensity gives the magnitude of the wavelet coefficients. The basic structure of an AF electrogram is as follows. The upper band corresponds to the frequency at which beats appear in the original signal, the beat body corresponds to the fluctuation frequency of an individual beat and the sharpness of each beat is given by the wavelet coefficients at the small scale range of the wavelet transform.

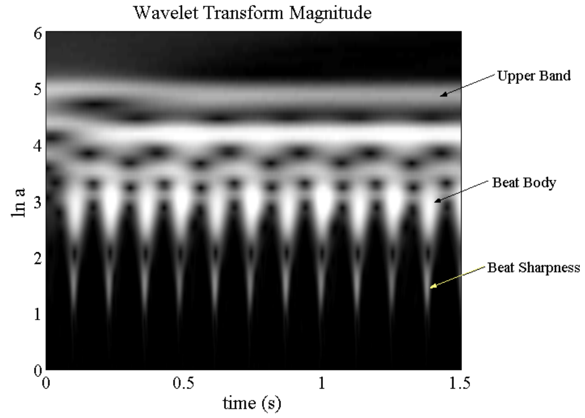

Figure 3: Wavelet transform of AF electrogram.

One long range goal of our work is to determine methods for extracting quantitative information from AF electrograms that can be used to identify highly organized yet intermittent sources of AF. In this study, we examine the problem of extracting time resolved beat spacing intervals from wavelet transforms of AF electrograms.

The approach taken is to apply the inverse wavelet transform

$$f(t) = \frac{1}{C_\Psi} \int_{-\infty}^{\infty} \int_{0}^{\infty} W(a,\tau) \frac{1}{\sqrt{a}} \psi\left(\frac{t-\tau}{a}\right) \frac{da}{a^2} d\tau \qquad (3)$$

to perform partial reconstruction on selected time-scale windows in order to extract quantitative information. It was demonstrated by Pelstring et al.[6], in the context of ocean engineering, that by computing the magnitude of inverse wavelet transform, one can accurately obtain the amplitude envelopes of individual modes in a signal. For the present application, we choose a time-scale window centered on the beat bodies and computed the amplitude of the partially reconstructed signal. The result is a less complex fluctuation than that of the original signal that can be readily analyzed with a simple peak detector to obtain the time resolved beat spacing.

In order to test the algorithm for extracting time-resolved beat spacing, families of synthesized electrograms were constructed by extracting a beat from an actual electrogram and replicating it in a new signal as diagrammed in figure 4. This approach allowed us to prescribe exactly where the beats would be placed so that we could then validate the spacing intervals returned by our algorithm.

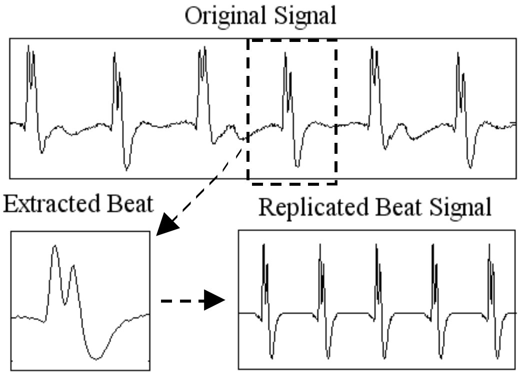

Figure 4: Method of synthesizing electrograms.

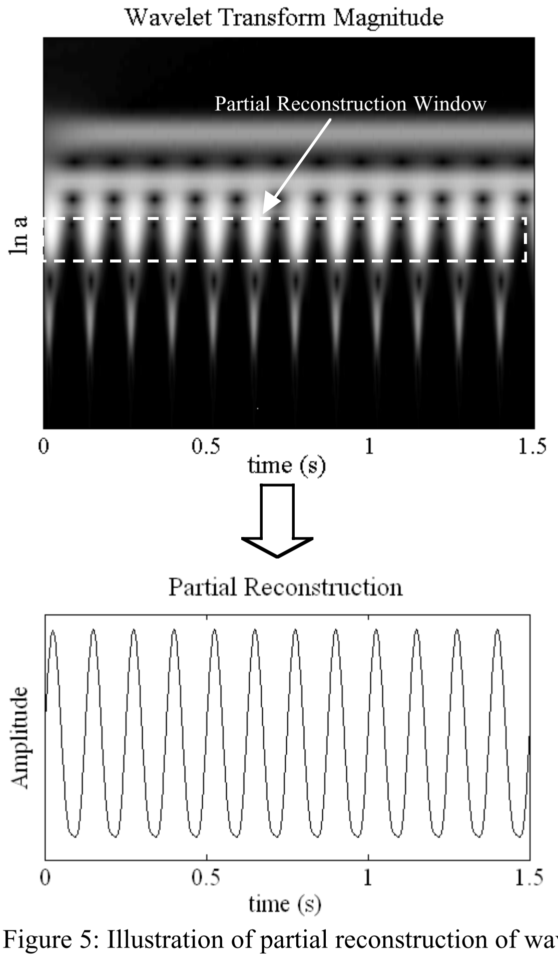

Figure 5: Illustration of partial reconstruction of wavelet transforms to readily identify beats in an AF electrogram.

Figure 5 demonstrates the partial reconstruction technique with a synthesized signal consisting of constant beat spacing of $\Delta T = 0.125$ s. The magnitude of the fluctuation shown below the wavelet transform demonstrates that each beat is identified by a distinct peak in the amplitude plot. Standard peak detection algorithms are then applied to extract the location of each peak.

4. TEST SIGNAL STUDIES

In order to determine how well the algorithm given in figure 5 would work on a more realistic case, we synthesized electrograms having randomly varying beat spacing *and* beat amplitude and then analyzed them with the wavelet transform approach presented above. Four different cases having different sequences of random numbers for the beat spacing and amplitude were synthesized. The beat spacing intervals were measured for each case and plotted against the prescribed beat spacing intervals in figure 5. The majority of range falls on the 45 degree line indicating a high degree of accuracy in the extracted time intervals. It is evident, however, that the range below a time interval of about 0.11s is less accurate than the rest of the plot. The maximum percent error within this range was determined to be 2% which is still a reasonable accuracy.

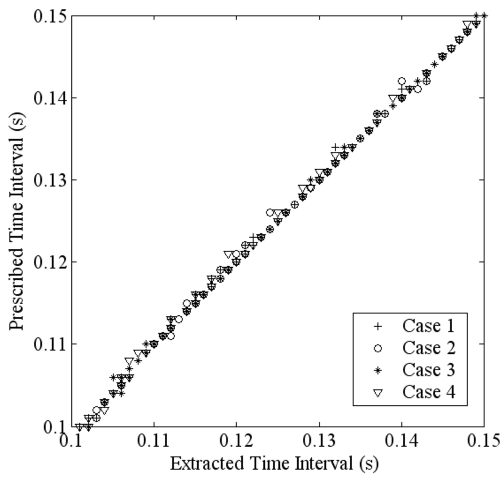

Figure 6: Comparison of prescribed and extracted beat spacing intervals from analysis of synthetic electrograms

5. ANALYSIS OF AF ELECTROGRAMS

In this section, the technique of measuring beat spacing intervals with wavelet analysis is applied to AF electrograms such as those presented in figure 2. Figure 7 shows the results from 3 bipoles (a12,d12,f12) of acute AF and 3 bipoles (a12,a34,e12) of chronic AF, where the beat spacing interval is plotted as a function of time. For acute AF case, the beat spacing interval is centered at ΔT=0.125s (8Hz) and shows very little fluctuation for all three bipoles examined here. The chronic case shows significantly larger ΔT than acute AF, as may be expected by noting the differences in acute and chronic AF from the signals presented in figure 2. One very interesting

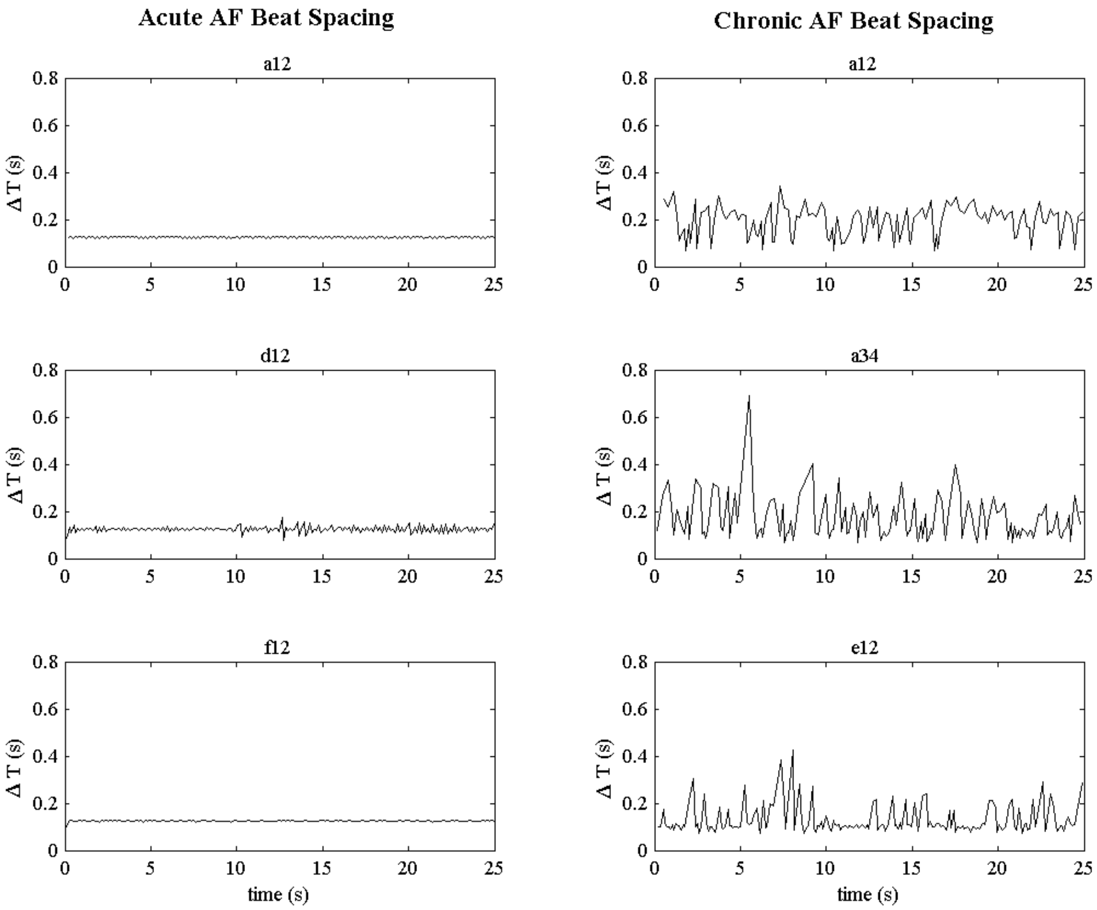

Figure 7: Beat spacing intervals for acute and chronic AF electrograms obtained with wavelet analysis

observation comes from bipole e12 in the chronic AF results. There are several time intervals between 10s and 20s where the spacing interval exhibits little fluctuation and the beat spacing interval is small indicating a relatively high frequency. For example, the time interval between 9.5 s and 12.5 s has an average ΔT = 0.1068s (9.363 Hz). Future work will examine if such intervals represent the appearance of intermittent organized reentrant cardiac waves.

In summary, we have developed an algorithm for measuring beat spacing intervals in AF electrograms that has been shown to be accurate and can be readily applied to the cases of acute and chronic AF. The algorithm utilizes partial reconstruction of wavelet transforms to extract the amplitude envelope corresponding to beat bodies to give a new signal where beats can be readily identified and the time interval between beats can be accurately quantified. The results presented on chronic AF electrograms suggest that the wavelet-based methods developed in this paper may be useful for identifying spatially localized sources of AF from basket catheter electrograms.

6. ACKNOWLEDGEMENT

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