FILTERING OF SURFACE LAPLACIAN ELECTROCARDIOGRAMS FROM HUMANS TO PRODUCE ATRIAL ACTIVATION PATTERNS

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***Abstract*-Four digital filtering techniques were evaluated to improve the signal-to-noise ratio (SNR) of directly obtained Laplacian electrograms (LECG), which were bandpass filtered before analog to digital conversion. The moment of activation (MOA) in the LECG was detected to create isochronal body surface maps, which show activation patterns. Unprocessed atrial LECG activity coincided with P-waves in the Lead II ECG (L2). Partial atrial flutter activation patterns were also constructed. The LECG system promises to reveal underlying cardiac activation patterns, including those of the atria, which are far less prominent than those from the ventricles.**
***Keywords* – ECG, Laplacian, Atrial activation pattern**

I. INTRODUCTION

The 12-lead electrocardiogram (ECG) yields limited spatial information about the ventricles and even less about the atria. To understand and treat certain arrhythmias, further diagnostic tools are necessary, such as invasive electrophysiology (EP) studies. Non-invasively derived spatial information from body surface potentials may reduce the time and risks for invasive EP exploration. Such a non-invasive system must have high spatial and temporal resolution to determine the origin of an arrhythmia. The surface Laplacian may fit these criteria.

The surface Laplacian, a non-invasive imaging technique, was first proposed by Hjorth [1] for electroencephalography studies, and later by He and Cohen for Laplacian ECG (LECG)[2]. Tarjan et al. [3] introduced our concentric LECG sensor. Rasquinha [4] identified arrhythmias with the sequence of delays from the moments of activation (MOA) by using animal data. Active LECG sensors were developed by Lu et al. [5]. Improvements in the sensor, filtering and MOA detection were accomplished by Besio [6]. The sensor approximates the second spatial derivative of the Laplacian potential on a planar surface. This concentric ring configuration allows for rejection of signals from distant sources with a tradeoff that the local signals are of low level and need enhancing.

II. METHODS

A. Subjects and Data Acquisition

Our data were obtained from consenting healthy and heart diseased subjects. Over 70 subjects have been recorded to date. This paper presents atrial activity from young healthy and atrial flutter subjects. The healthy data were recorded on a regular 7 x 5 grid at 35 locations on the chest surface. Seven LECG channels and the Lead II ECG (L2) were recorded and digitized simultaneously. The atrial flutter data were recorded from an irregularly spaced active LECG sensor array. All signals were amplified by 1120, bandpass filtered from 5 to 500Hz and digitized at 1KHz (1 ms resolution) for 30 sec epochs (30K samples). The data acquisition was controlled with a program written in LabView® (National Instruments).

B. Digital Filters

Four types of digital filtering techniques were evaluated to optimize the signal-to-noise ratio (SNR): Butterworth Bandpass (Bworth) from 5 to 125 Hz, Adaptive Wiener (AW), Alternative Adaptive (AA) and Ensemble Averaging (EA). The AW filter utilized Bertrand's filtering technique [7], a sub-average spectral analysis, as in (1):

$$H(f)=\frac{N}{N-1}\cdot\left(\frac{S_x^-(f)}{\overline{S_x}(f)}-\frac{1}{N}\right), \tag{1}$$

where *H(f)* is the filter's transfer function in the frequency domain, *N* is the number of individual time windows, S_x^- is the spectrum of the time-averaged windows, $\overline{S_x}(f)$ is the spectrum of the ensemble averaged signal, and *x* is the data in a specific time window. The AA filter utilized Rivera-Colon and Lindquist's technique [8]. The "floor" (minimum), or the white noise, was removed as in (2):

$$H(f)=\frac{\langle R(f)\rangle-\min\langle R(f)\rangle}{\langle R(f)\rangle}, \tag{2}$$

where *R(f)* is the signal and noise spectra combined and "min" is the "floor."

For the SNR, the signal was measured over an interval of ±40ms from the L2 R-wave peak (L2R), near the QRS. The noise was measured over 110ms in the PQ interval, ending 50ms prior to L2R. This interval was chosen because it is where the signal should dominate.

C. Isochronal Activation Maps

The activation patterns are based on the MOAs that we define as the instant the depolarization wavefront crosses the line normal to the central axis of the sensor. At the MOA, the LECG rapidly slews between opposite extrema. For atrial flutter maps, the time of activation at a specific sensor is referenced to the atrial flutter peak in L2 for that

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cycle. The LECG was aligned to this atrial flutter peak and ensemble averaged.

III. Results

The AW filter produced the highest SNR, as illustrated in Table 1. An analysis of variance (ANOVA) was conducted and the AW filter was statistically superior to the other three filtering techniques. The mean SNR for the AW filter was 20.56dB, with a range from 37.95dB to 2.35dB.

Table 1. The mean SNRs of the four filters on the healthy data.

Filter	EA	AA	Bworth	AW
SNR (dB)	16.51	16.51	18.21	20.56

The top panel of Fig. 1 shows the LECG waves after AW filtering. A pronounced peak is evident at approximately 260ms, or -140ms with respect to the L2R and coincides with the P-wave in the bottom panel. Atrial-waves were also evident in some unprocessed recordings.

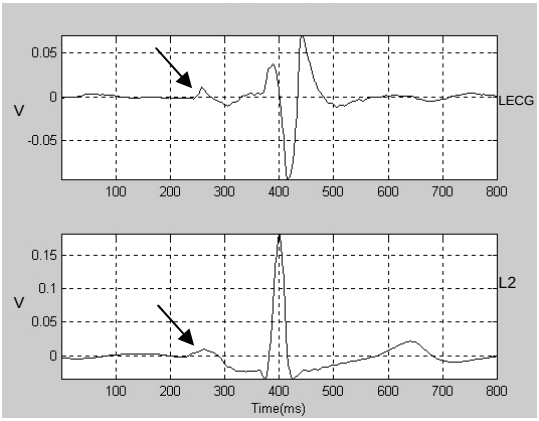

Fig. 1. The AW filtered LECG and L2. Atrial-wave (Top) at about 140ms before the L2R (Bottom).

As expected, the atrial flutter subjects did not show unusual ventricular depolarization patterns in their body surface isochronal MOA maps when synchronized to the L2R. Atrial flutter was evident in multiple unprocessed recordings as shown in Fig. 2. Panel H (bottom right) shows atrial flutter in L2. Panel C (8.7, 1.3), D (7.7, -6.3) and G (10.2, -3.2) also show atrial flutter.

Fig. 3 is a partial atrial flutter map of subject AS. The longer arrows illustrate two regions where activation spreads quickly during atrial flutter: at (7, 4), the contour originates at t= -60ms; the (12, -8) neighborhood is activated at about t = -40ms.

IV. Discussion & Conclusions

The AW filter performed significantly better than any of the other three filtering techniques evaluated on our data. Although not presented here, the AA filter demonstrated very high SNRs on the simulated data utilizing white noise. However, on the recorded human data its performance was no better than the EA filter. The LECG sensor system was able to detect atrial activity as demonstrated in Figs. 1 and 2.

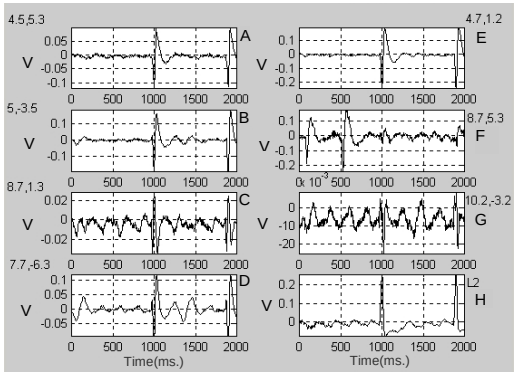

Fig. 2. Unprocessed recordings from subject AS during atrial flutter.

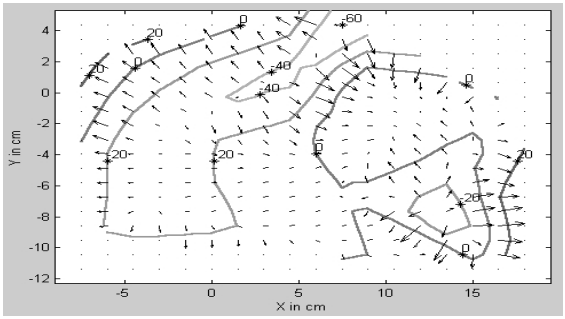

Fig. 3. A spatial portion of the atrial flutter cycle of subject AS.

With atrial activity manifested in multiple LECG channels, detection of atrial activation patterns may be possible to aid diagnosis. The atrial flutter map shows an area on the body surface where the atrial activation pattern was detected. With sufficient spatial resolution, we expect to map a complete flutter cycle to show the point of re-entry.

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