Entropy & Frequency Analysis of New Electrocardiogram Lead Placement for Atrial Fibrillation Detection

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Background

Atrial fibrillation (AF) is defined as a varying heart rate which can cause reduced blood flow to the body. It is the most common arrhythmia and it occurs when the electrical signals of the heart's atria are disorganized. AF affects close to 3million people in the US and around 6million people in Europe. AF can cause many life-threatening problems, one of which is stroke.

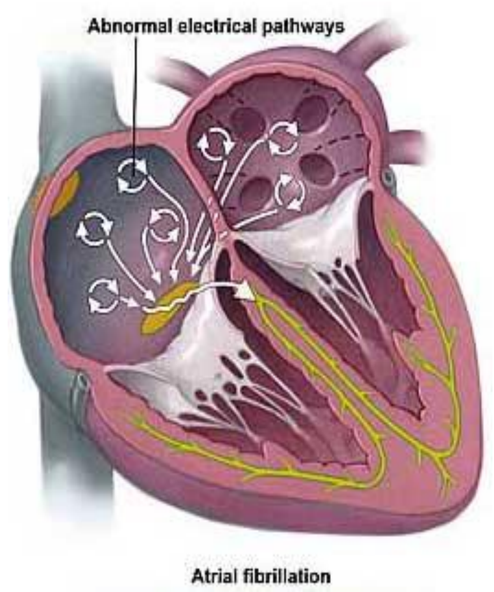

Figure 1: Atrial Fibrillation Electrical Pathway.

Figure 2: Electrocardiogram of AF (top) and SR (bottom) Patients. Purple arrow displays healthy P-wave while red arrow displays irregular F-waves during AF.

Objectives

This is a preliminary study that explores lead placements for atrial fibrillation quantification. The objective of this study was to locate the best lead placement to maximize AF detection using the least number of leads.

Experiment Setup

Data was collected at the Rochester Cardiopulmonary Group from two patients who were experiencing paroxysmal AF. Clinical lead placement is displayed in Figure 3 and the setup used in this experiment is shown in Figure 4. Data was collected using two GE 12-channel Holter Recording Devices for an hour. The sampling frequency of the devices were 1024Hz. The recordings were divided into sections which contained 100,000 samples (~98secs) each.

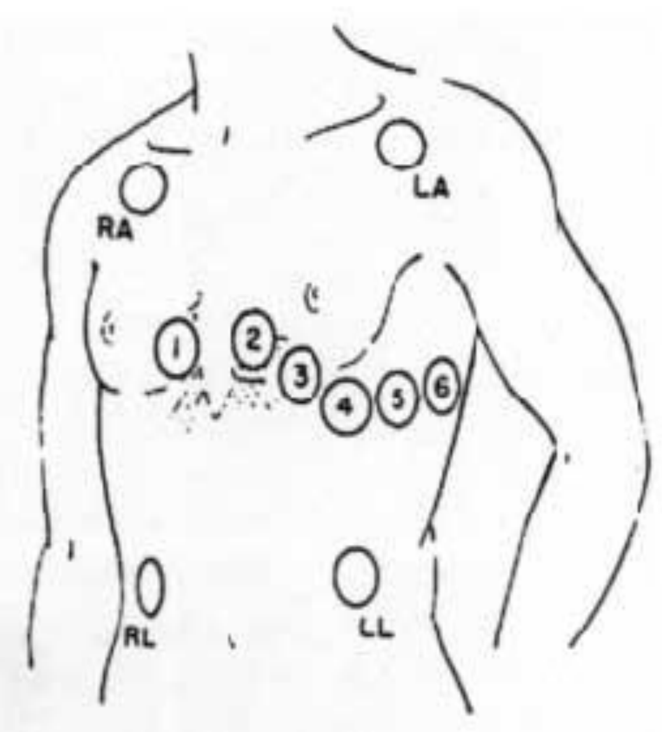

Figure 3: Clinical ECG Lead Placements

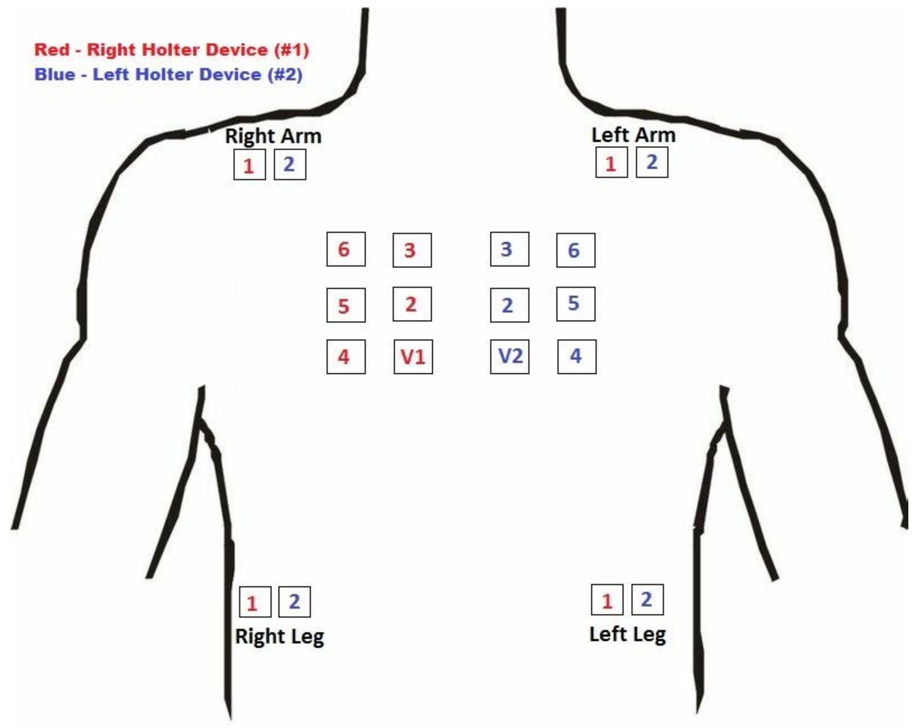

Figure 4: ECG Lead Placement for study

Data Processing

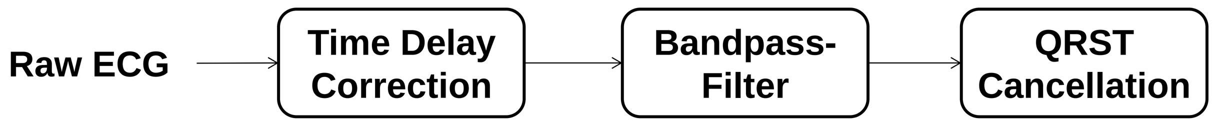

Figure 5: Block Diagram of Preprocessing

1. **Time Delay:** Both Holter Recording Devices were started manually, which introduced a time delay in the recording. Lead I was used to align the R-peaks of the Left Holter and the Right Holter.
2. **Bandpass Filter:** Frequency cutoffs at 0.5Hz and 50Hz. Low-pass filter used to remove noise while the high-pass filter removes baseline wander.
3. **QRS Complex Cancelation:** R-peaks of the ECG signals were used to create a template of the QRS complexes. The template was then subtracted from each QRS occurrence. This process is displayed in Figure 6.

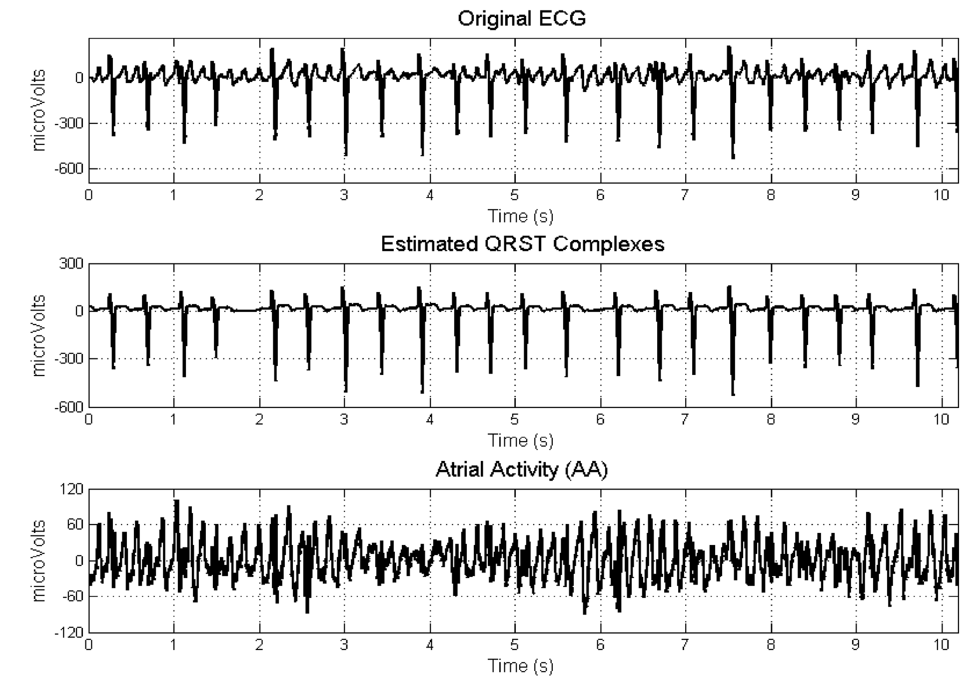

Figure 6: QRS Cancellation Process. Top figure displays the original ECG. Middle figure displays the QRS template signal and bottom figure demonstrates the subtraction of the two.

4. **Lead Combination:** V1 and V2 in Figure 4 are the same location as the clinical placement of V1 and V2. Also, the leads in Figure 4 are unipolar leads (bipolar with respect to Einthoven's Triangle) and are combined to create 66 bipolar connections. The leads are subtracted from one another starting with: V1B-V2B and ending with V5R-V6R.

$$R_{ij} = R_i - R_j$$

$$i, j \in \begin{cases} B_1 \dots B_6 \\ R_1 \dots R_6 \end{cases}$$

AF Detection Methods

Entropy:

Entropy is a measure of the uncertainty of a random variable. It is used here to quantify the atrial activity of AF patients. The entropy of each signal section was calculated using the following equation:

$$H(X) = -\sum_i P(X_i) * \log_2 P(X_i)$$

Spectral Analysis:

The dominant frequency is known as the frequency with the highest peak. This is applied to the atrial activity (between 4Hz and 10Hz) of the FFT (Fast Fourier Transform) of each of the signal sections. The dominant frequency was analyzed for each section.

Results

Entropy - Patient 1			
	Combinations	Avg	STD
1	V1R-V3R	3.242	0.170
2	V1L-V3R	3.152	0.305
3	V1L-V5R	3.050	0.255
4	V3L-V5L	3.043	0.271
5	V1L-V2R	3.015	0.261

Table 1: Top Five Highest Entropy Combinations for Patient 1

Entropy - Patient 2			
	Combinations	Avg	STD
1	V5L-V5R	3.037	0.451
2	V1L-V6R	3.009	0.524
3	V5L-V6R	3.005	0.446
4	V1L-V5R	2.986	0.512
5	V5L-V1R	2.971	0.410

Table 2: Top Five Highest Entropy Combinations for Patient 2

Dominant Frequency - Patient 1			
	Combinations	Avg	STD
1	V2L-V2R	6.133	0.672
2	V3L-V2R	6.088	0.636
3	V2L-V5R	5.935	0.828
4	V5L-V5R	5.870	0.690
5	V2L-V3R	5.846	0.692

Table 3: Top Five Highest Dominant Frequency Combinations for Patient 1

Dominant Frequency - Patient 2			
	Combinations	Avg	STD
1	V2L-V6R	6.345	0.217
2	V2L-V5R	6.314	0.177
3	V2L-V3R	6.308	0.297
4	V2R-V4R	6.279	0.299
5	V1L-V3R	6.272	0.252

Table 4: Top Five Highest Dominant Frequency Combinations for Patient 2

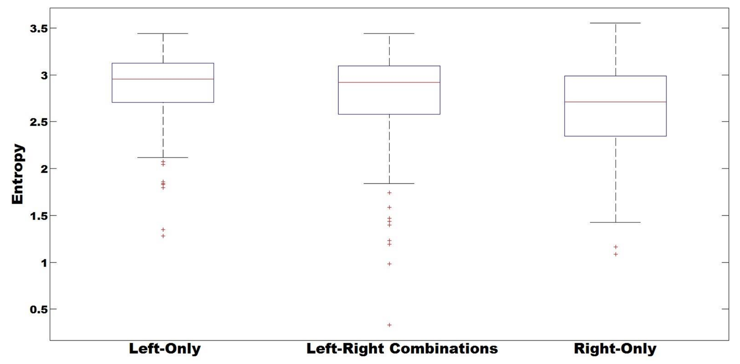

Figure 7: Entropy for Patient 1

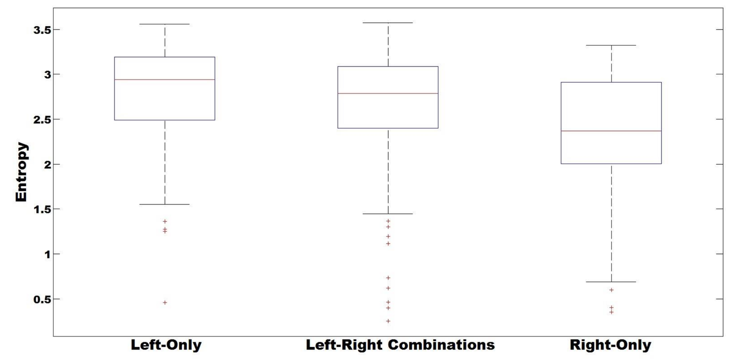

Figure 8: Entropy for Patient 2

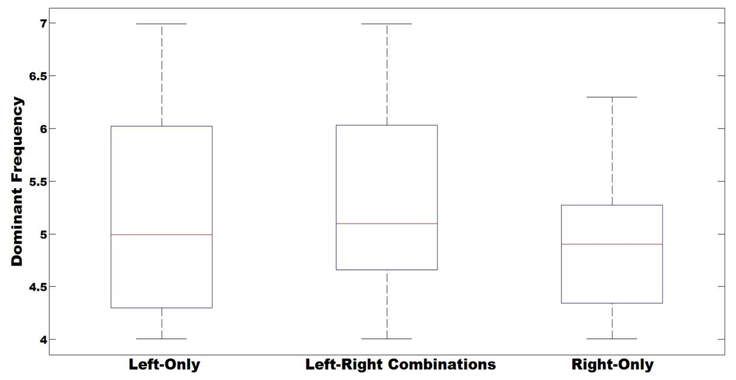

Figure 9: Dominant Frequency for Patient 1

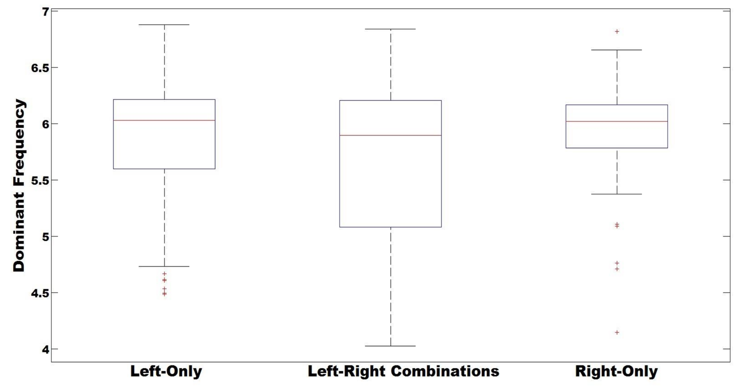

Figure 9: Dominant Frequency for Patient 2

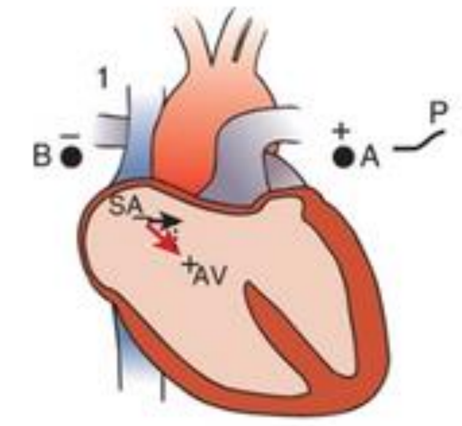

Figure 10: P-wave Dipole Direction

Conclusion

- Combinations in the same direction of the P-wave dipole produced higher entropies and higher dominant frequencies.
- Combination V1L-V5R produced high entropies in both patients.
- V2L-V5R and V3L-V5R combinations produced one of the highest dominant frequencies.
- This preliminary study suggests that a reduced lead set up from a left-right combination could allow for an ambulatory AF detection device while preserving the AF detection accuracy.
- In order to generalize our observations in this study, more AF data needs to be collected and analyzed using our developed lead setup.