Comparing Power Spectral Density of the 64-Channel Surface ECG with Left Atrial Electrograms in Patients in Atrial Fibrillation

Marjan Bojarnejad[1], James Blake[2], John P Bourke[1], Alan Murray[1], Philip Langley[1]

[1] Institute of Cellular Medicine, Newcastle University, Newcastle upon Tyne, UK
[2] Medical Physics Department, Freeman Hospital, Newcastle upon Tyne, UK

Abstract

Study of the mechanisms behind AF is typically based on invasive recording techniques. From a clinical point of view, it is highly desirable to have an alternative, noninvasive characterization of AF. Our aim was to investigate if the left atrium (LA) electrical activity can be seen preferentially in different sites on the surface ECG. Surface recordings of the ECG with 64 electrodes were obtained from 14 patients in atrial fibrillation (AF). After subtracting ventricular activity (QRST), power spectral density (PSD) of atrial activity was calculated using the Welch periodogram, sliding Hamming window (50% overlap). The dominant frequency (DF) was measured from the PSD in the frequency band of 4-8 Hz for each of the 64 channel surface ECGs. Recordings from the LA were obtained simultaneously from a pulmonary vein ablation catheter (PVAC). The DF of atrial activation was calculated from the PSD of the PVAC electrode number 3 (PVAC3) in the same manner as the surface ECG. Baseline recordings of 2 minute duration were analysed. DF differences were calculated between each 64 channels surface ECG and PVAC3. The Pearson's linear correlation was computed for PSD of each 64 channel surface ECG and PVAC3. The statistical difference between PSD of 32 front and 32 back channels surface ECG and PVAC3 was analyzed for both correlation and DF difference using the paired t-test. There was a highly significant difference between surface ECG and PVAC3 (p=0.00).

1. Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia affecting 6% of the population over the age of 80 [1]. It is distinguished by irregular electrical activity of the atria, and the fibrillating or trembling of the atrial muscle, instead of a normal contraction. Ablation has become a common treatment option for AF with the aim of restoring sinus rhythm. An ablation procedure usually involves delivery of energy to create lesions at specific target sites within the atria, for example the pulmonary veins.

It is not well understood how electrical activity from different parts of the atria contribute to the surface ECG [2]. The surface ECG has been scrutinized to allow inferences about underlying mechanisms of the AF. Processing and interpretation of the left atrium information is available through cardiac catheterization which carries risk (e.g. bleeding, infection, damage to blood vessels) and sometimes complications (e.g. heart or lung problems, blood clots, reactions to dye). Consequently being able to collect left atrium information non-invasively from the surface ECG would be a very helpful guide prior to an ablation procedures [3]. It is thought that the dominant frequency (DF) of AF reflects the degree of organization of underlying atrial activity [4]. Consequently being able to analyse the DF non-invasively from the surface ECG may be a helpful guide prior to ablation procedures [3].

This preliminary study focuses on investigating if the left atrium (LA) electrical activity can be seen preferentially in different sites on the surface ECG.

2. Methods

2.1. Study group

14 patients were recruited from patients admitted for AF catheter ablation to our hospital (5 persistent AF, 9 paroxysmal AF). The group comprised 10 male, 4 female, mean (standard deviation) age was 59(7) years, and BMI was 28(4) kg/m^2.

2.2. Body surface ECG recordings

Two minutes duration surface recording of the ECG was obtained using BioSemi® (BioSemi, Amsterdam, Netherlands) ActiveTwo™ recording system with a sample rate of 2048 Hz, 24-bit/sample. 64 monopole leads and 3 bipolar limb leads were recorded. The electrodes were arranged in 8 flexible rubber strips (length of 43 cm) with 8 electrodes on each strip (each 45 mm apart). Electrodes from A1 to A32 were placed approximately parallel with one another on the torso from the level of the top of the sternum, down to the waist. Electrodes from B1 to B32 located in the other 4-strips were placed on the back, in the corresponding locations as the front strips (Figure 1).

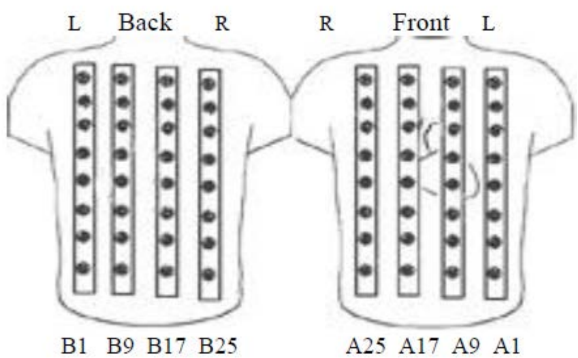


Fig. 1. 64 electrode placement on the body surface. Front electrodes numbered from A1 to A32. A1-A8 (1st strip) left side of torso, A25-32 (4th strip) right side of the torso. Rear electrodes numbered from B1 to B32 were located as the front strips.

2.3. Left atrium recordings

LabSystem™ PRO EP recording system (Bard Electrophysiology Division, MA, USA) was used to record LA signals simultaneously with the surface ECG. An X-ray view and drawing of the catheter inside the LA is shown in Figure 2.

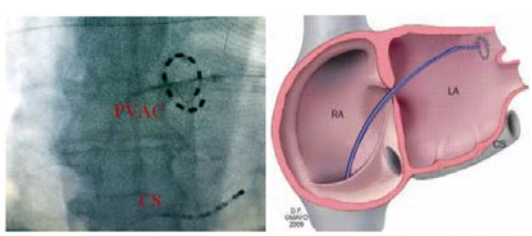


Fig. 2. Left: X-ray view, top: decapolar pulmonary vein ablation catheter® (PVAC) to isolate the pulmonary veins. Right: a drawing of the catheter inside the heart to isolate the pulmonary veins (www.wordpress.com).

2.4. Signal processing method

The surface ECG and LA recording were processed off-line. The surface ECG was down-sampled from 2048 Hz to 512 Hz and band-pass filtered (0.5-100 Hz) for baseline wander removal and high frequency noise suppression. The Wilson Central Terminal was computed and subtracted from the 64 channels to obtain 64 precordial leads.

Beat detection was carried out by means of a proprietary threshold-based QRS detector. QRST cancellation was performed by averaged-QRST template subtraction [5]. The QRST window was selected manually for each patient. The power spectral density (PSD) of atrial activity was computed using the Welch periodogram, sliding Hamming window (50% overlap) for each of the 64 channel surface ECG. The DF was calculated and defined as the frequency component with the highest energy in the range of 4-8 Hz for each surface channel. Absolute amplitude values of the LA recordings were band-pass filtered 40-250 Hz [5]. Recordings from the 3rd electrode of 5-decapolar PVAC were chosen for analysis. The reason for choosing PVAC3 was this channel had good contact and signal quality across all patients. The DF was calculated from the PSD of PVAC3 in the same manner as the surface ECG.

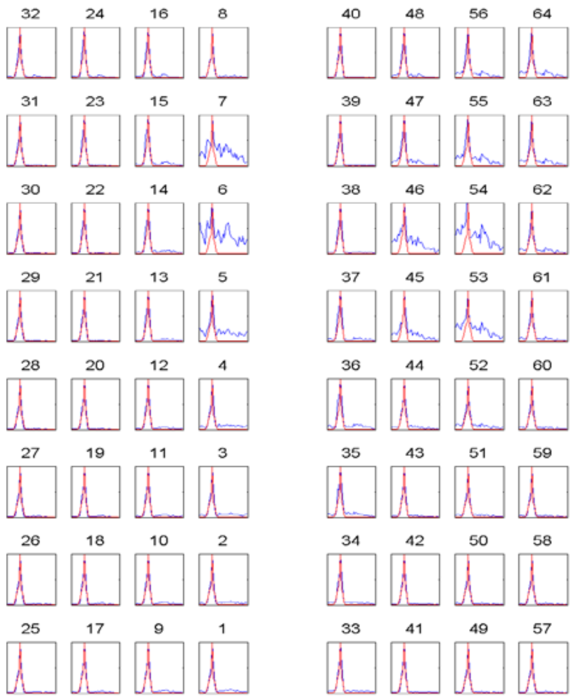
2.5. Statistical analysis

Two minutes duration baseline recordings of 64 channel surface ECG with PVAC3 were analysed. The Pearson's linear correlation of PSD considering 4-8 Hz frequency band was performed on each 64 channel surface ECG vs. PVAC3 (Figure 4a). Median differences of DF for surface ECG vs. PVAC3 was calculated across the 64 surface channels (Figure 4b). The 64 channel surface ECG was considered as 32 front and 32 back channels. Median values of the front and back electrodes were calculated for each subject for both the correlation and the DF difference. The mean and standard deviation (SD) were computed (Table 1). Paired t-test was performed on the median of the correlation values and the DF differences across the subjects between front and back electrodes.

3. Results

Figures 3 (a) and (b) show examples of spatial surface ECG and LA PSD plots for two representative cases. Note, for this figure the LA PSD is the same in all plots but is shown overlaid by the surface PSD for comparison. PSD surface ECG vs. PVAC3 shows that in some patients surface ECG and LA are highly correlated across all surface sites and in some patients there is a poor correlation. This variation can be observed in DF as well. However, DF on the surface ECG was significantly greater than LA DF with a mean (SD) of 0.16 (0.16) Hz ($p<0.0001$).

(a)



(b)

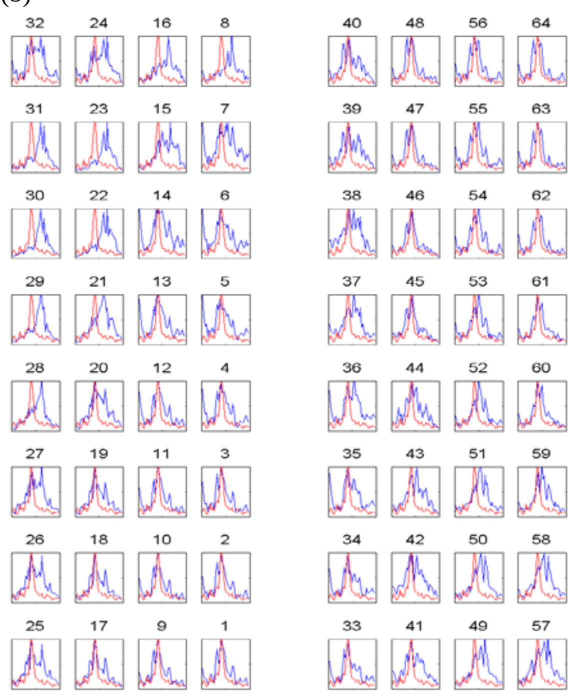
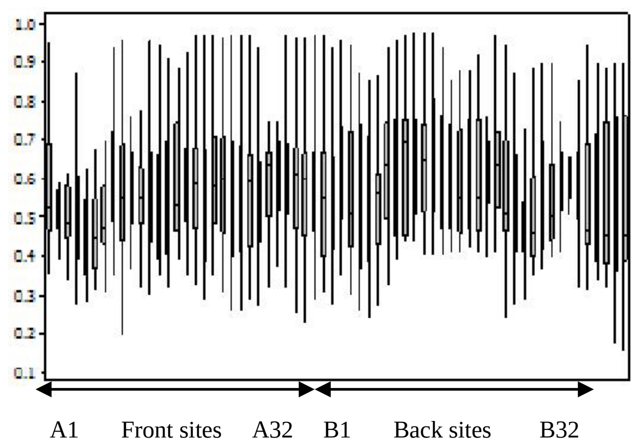


Fig 3. (a) Spatial PSD of 64 channel surface ECG and PVAC3 for subject 2. (b) Spatial PSD of 64 channel surface ECG and PVAC3 for subject 10. Number above each square identifies surface ECG channel number. This order matches the electrode layout in Figure 2. Blue is surface ECG and red is PVAC3. X-axis is normalized power in arbitrary units. Y-axis is frequency in 4-8 Hz.

Figures 4 (a) and (b) show box plots of 64 channel surface ECG and PVAC3 correlation and DF difference, respectively. Boxes represent correlation in Figure 4 (a) and DF difference in figure 4 (b) of each 64 channel ECG with PVAC3 across 14 subjects.

Table 1 shows the correlation values between PSD (64 channel surface ECG) and PSD (PVAC3), as well as the DF difference between PSD (64 channel surface ECG) and PSD (PVAC3) for each patient. 32 front surface electrodes and 32 back surface electrodes were considered separately. Values were obtained from median across front and back channels.

(a)



(b)

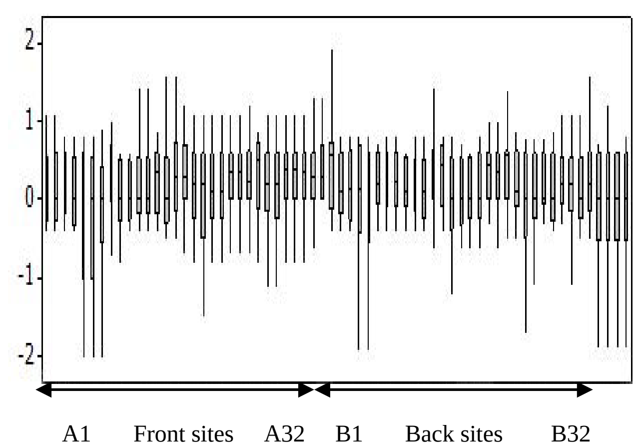


Fig 4. (a) Box plot of the PSD correlation values (64 channel surface ECG vs. PVAC3) for each surface channel, across the 14 patients. X-axis is the surface ECG channel number. Y-axis is the correlation values. (b) Box plot of DF difference of the 64 channel surface ECG vs. PVAC3, across the 14 patients. X-axis is the surface ECG channel number. Y-axis is DF differences (ECG vs. PVAC3) in Hz. A1 to A32 are 32 front surface electrodes. B1 to B32 are 32 back surface electrodes.

Table 1. The median correlation and the median DF difference of PSD (64 channel surface ECG) vs. PSD (PVAC3) for each patient, across the 32 front and 32 back surface ECG.

Patient	*Correlation*		*DF difference (Hz)*	
	Front	**Back**	**Front**	**Back**
1	0.46	0.46	1.10	0.80
2	0.96	0.93	0.00	0.00
3	0.64	0.60	-0.10	0.05
4	0.52	0.58	0.60	0.60
5	0.41	0.38	0.00	0.00
6	0.66	0.86	0.00	0.00
7	0.50	0.45	0.50	0.65
8	0.60	0.65	-0.30	-0.30
9	0.67	0.73	0.50	0.50
10	0.50	0.44	-0.80	-0.60
11	0.63	0.53	-1.50	-1.65
12	0.58	0.53	0.60	0.60
13	0.45	0.47	0.35	0.60
14	0.61	0.74	0.60	0.00
Mean	0.59	0.60	0.11	0.08
SD	0.14	0.16	0.66	0.64

The results of the paired t-test on the front and back channels median correlation values and the front and back channels median DF differences across the subjects are p= 0.61 and p=0.71, respectively.

4. Discussion and conclusions

In this study, two minutes of the 64 channels surface ECG and LA electrogram recordings from 14 patients were considered with the goal of comparing the power spectral density. From the DF we showed a highly significant difference between intracardiac and body surface with no cases of the body surface DF being less than the intracardiac DF. This might suggest that the body surface was detecting higher frequency drivers than were recorded at our LA recording site. The Pearson's linear correlation of PSD of 32 front and 32 back surface ECG vs. PVAC3 shows that there no significant difference between front and back surface ECG with LA (p=0.61).

Moreover comparing the DF difference of 32 front and 32 back surface ECG vs. PVAC3 shows that there was no significant difference between front and back surface ECG with LA (p=0.71). It can be concluded that although 64 channel surface ECG spatially is different in correlation and DF with LA overall difference is not significant.

Further work will study the other parameters of PSD, e.g. spectral concentration and distinct frequency components for 64 channel surfaces ECG and compare them with all PVAC channels to find out if different components of the LA spectrum do match with any components of the surface ECG.

References

[1] Valentin Fuster, Lars E. ACC/AHA/ESC Guidelines for the Management of Patients with Atrial Fibrillation. JACC 2001; 38; 1266.

[2] Petrutiu S, NG J, Nijm G M, Al-Angari H, Swiryn S, Sahakian A. Atrial Fibrillation and Waveform Characterization: A time Domain Perspective in the Surface ECG. IEEE engineering in medicine and biology magazine 2006; 0739-5175/06.

[3] Ng J, Kadish A H, Goldberger JJ. Effect of Electrogram Characteristics on the Relationship of Dominant Ffrequency to Atrial Activation Rate in Atrial Fibrillation. Heart Rhythm 2006; 3(11):1295-305.

[4] Beckers F, Anne W, Verhryden B, Aubert AE. Determination of Atrial Fibrillation Frequency Using QRST-Cancellation with QRS-Scaling in Standard Electrocardiogram Leads. Computers in Cardiology 2005; 32:339−342.

[5] Richter U, Faes L, Cristoforetti A, Mase M, Ravelli F, Stridh M, Sornmo L. A Novel Approach to Propagation Pattern Analysis in Intracardiac Atrial Fibrillation Signals. Annals of Biomedical Engineering 2011; 39:310-323.

Address for correspondence:

Marjan Bojarnejad
Medical Physics Department
Freeman Hospital
Newcastle upon Tyne
United Kingdom
Marjan.bojarnejad@ncl.ac.uk