Manifestation of Left Atrial Events in the Surface Electrocardiogram during Atrial Fibrillation

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Abstract

In most patients, atrial fibrillation (AF) is initiated by pulmonary veins foci. We investigated whether these left atrial events are reflected in the surface electrocardiogram (ECG) and whether additional information can be obtained from recording posterior leads in patients with AF. In 7 patients, we identified 51 5-second segments with a significant frequency gradient between right (RA) and left (LA) intra-atrial electrograms, as well as frequency changes from segment to segment in the same patient. QRS-T cancellation methods were used to isolate atrial activity in the surface ECG, and peak frequencies were computed. Peak frequencies of posterior leads were very similar (6.0 ± 1.3 Hz for V7, 5.9 ± 1.4 Hz for V8, 6.0 ± 1.1 Hz for V9, 6.0 ± 1.3 Hz for V10). Lead V9 seemed to have the best signal quality and was chosen for further analysis. We found a strong correlation between V1 and RA and between V9 and LA, 0.98 and 0.93 respectively, while the lowest correlation was found between lead V1 and LA, 0.64, $p <$ 0.00001. Magnitude-Squared Coherence values were highest between V1 and RA and lowest between V1 and LA.

1. Introduction

The role of the left atrium and particularly the pulmonary veins (PV) in the initiation and maintenance of atrial fibrillation (AF) is not fully understood, though a great deal of evidence suggests a central role. In many patients, rapid focal firing within the PVs may trigger the onset of AF [1]. It has been shown that frequency domain measures can be used to determine the frequency of AF and to distinguish atrial fibrillation from other non-fibrillatory rhythms [2]. Recent studies have demonstrated a gradient of frequencies between the left and right atria of patients in AF undergoing PV isolation [3]. Higher frequencies were observed in the posterior left atrium when compared to the anterior left atrium and the right atrium. These dominant frequencies have been targeted during ablation procedures to terminate AF [4].

Evidence suggests that there is a correspondence between intra-atrial electrogram information and the surface ECG during AF [5]. However, the standard ECG leads are not specifically designed to record left atrial activity. Our laboratory and others have developed tools for quantitative analysis of atrial fibrillatory waves from the surface ECG as well as intra-cardiac recordings [6,7]. Typically these techniques involve analyzing lead V1, because it has the largest ratio of atrial amplitude compared to ventricular amplitude. Since this lead is in close proximity to the right atrium it is thought of as reflecting mostly right atrial activity [7,8]. In addition, during AF the amplitude of the atrial activity decreases in the surface ECG when compared to sinus rhythm, due to the cancellation of wavefronts. Therefore it is not clear to what extent posterior left atrial activity is reflected in the surface ECG and whether there are other better noninvasive methods to detect this activity since the left atrium is behind the right atrium from the field of view of lead V1.

The main purpose of this study was to determine whether left atrial events are reflected in the surface ECG and whether additional recording sites should be used in patients with AF. By comparing the information extracted from the surface ECG with simultaneous intra-cardiac recordings we should be able to learn more about what local events are reflected and which leads contain the most information.

2. Methods

2.1. Recordings

We identified 7 adult patients with AF referred to the electrophysiology laboratory for PV isolation. During this procedure we recorded 1 minute of right and left intra-atrial electrograms filtered at 30 to 500 Hz and 12 simultaneous surface ECG leads using the Prucka recording system (GE Medical, Inc. Milwaukee, Wisconsin). Using biplane fluoroscopy, intra-atrial catheters were placed as close as possible to the location of the surface ECG electrodes, in the right atrium which will be referred to as the RA recordings, and in the left atrium at the entrance of the left superior PV which will be referred to as the LA recordings.

In addition to the standard ECG limb leads we recorded leads V1, V2 and also the standard but infrequently used leads V7, V8, and V9. The V7-V9 electrodes extend in a horizontal line from V6. V7 is placed at the posterior axillary line, V8 is placed at the mid-scapular line, and V9 is placed at the paravertebral line. An additional surface lead location was defined, lead V10, which was also placed on the paravertebral line, above V9, on the same level as V1.

This project was reviewed and approved by the Institutional Review Board of Evanston Northwestern Healthcare.

2.2. Data processing

Digital signal processing was performed using MATLAB (The Mathworks Inc., Natick, MA). We analyzed 5-second segments to obtain peak frequencies from the surface ECG as well as dominant frequencies (DF) from the intra-atrial recordings. The surface ECG signals were bandpass filtered with cutoff frequencies of 1 and 50 Hz to avoid baseline wander and power line interference. From the surface ECG we isolated fibrillatory waves by using a template-matching algorithm similar to the one originally described by Slocum et al. [9] and obtained a remainder ECG. Following QRS-T cancellation, the power spectrum of each remainder ECG was calculated using the Fast Fourier Transform (FFT) method. We recorded the peak frequency in each lead as the location where the maximum peak of the power spectrum occurred. We also processed all intra-atrial electrograms to obtain local DFs [10] and compared them to the peak frequencies obtained from the different surface ECG leads.

Intra-atrial recordings were first bandpass filtered with cutoff frequencies of 40 and 250 Hz. These signals were rectified and then lowpass filtered with a cutoff frequency of 20 Hz. For each 5-second segment of the processed electrograms we calculated a power spectrum using the FFT method. The DF was recorded as the frequency at which the maximum of the power spectrum occurred.

Magnitude-Squared Coherence (MSC) was used to determine whether there was a constant phase relationship between surface ECG leads and intra-cardiac electrograms [11]. We computed the MSC spectrum between a remainder ECG and a processed electrogram for the same segment. We calculated the MSC by using the overlapped FFT method. The MSC can vary between 0 and 1, with 0 representing no linear relationship or no correlation between the two signals, and 1 indicating a linear or perfectly coherent relationship between the two signals at that frequency. Since the MSC spectrum is normalized, it is also insensitive to gain and is not dependent on the actual morphology of the signal.

From each 1-minute recording we identified moments of significant DF gradient, at least 0.2 Hz between the LA and RA intra-atrial recordings as well as moments where there was a significant change in frequency from one segment to the next. We analyzed the surface ECG leads to determine whether these frequency gradients can be distinguished between the leads corresponding to the closest location to the RA and LA recordings.

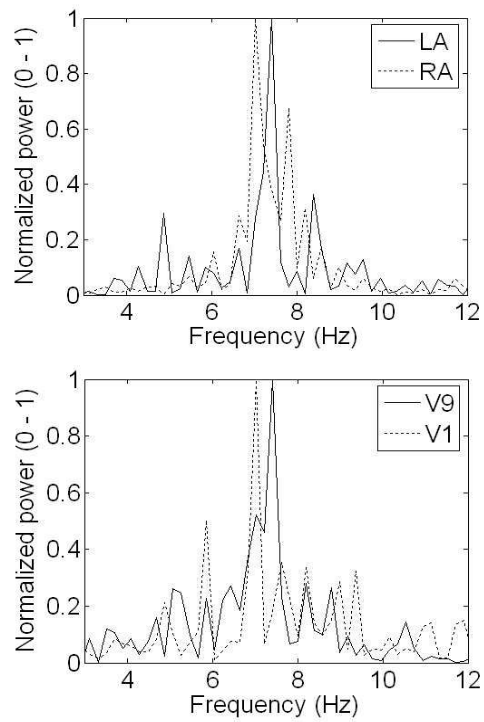

Figure 1. Normalized power spectrum for a 5-second segment where the LA was faster than the RA. This frequency gradient is reflected in the surface ECG.

3. Results

A total of 7 patients, 6 males and 1 female, who were in AF at the time of the procedure were included in this study.

We identified 51 segments with significant frequency differences between the LA and RA and between different time segments in the same patient.

Peak frequencies were compared between posterior leads and they were very similar (6.0 ± 1.3 Hz for V7, 5.9 ± 1.4 Hz for V8, 6.0 ± 1.1 Hz for V9, 6.0 ± 1.3 Hz for

V10). Lead V9 seemed to have the best signal quality in all patients and was therefore chosen for further analysis.

Dominant frequency (DF) in the RA ranged from 4.8 to 9.4 Hz (6.8 ± 1.3 Hz), while in the LA it ranged from 3.9 to 8.3 Hz (6.5 ± 1.1 Hz). Peak frequency in lead V1 ranged from 4.3 to 9.5 Hz (6.8 ± 1.1 Hz), while in lead V9 it ranged from 4.1 to 8.4 Hz (6.5 ± 0.9 Hz).

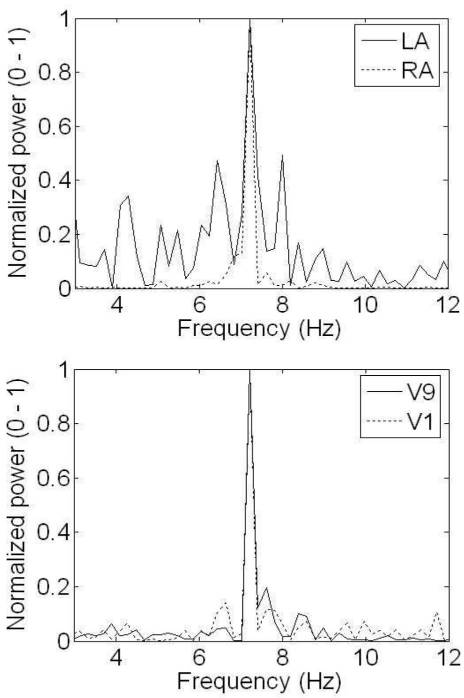

Figure 2. Normalized power spectrum from the same patient as Figure 1, but during a 5-second period with no frequency gradient between the LA and RA. These DFs are reflected in the surface ECG leads.

Figure 1 shows the normalized power spectrum for a 5-second segment where the DF in the LA was greater than the DF in the RA. It can be observed that this intra-atrial frequency gradient is reflected in the surface ECG as a gradient between leads V9 and V1. We also checked whether changes in DF from one segment to the next are reflected in the surface ECG leads. Figure 2 shows the normalized power spectrum for a 5-second segment from the same patient as Figure 1. We observe that we can monitor the intra-atrial DF frequency changes from the surface ECG by analyzing the leads closest to the electrogram location.

Correlation was found to be the highest between lead V1 and the RA recording with a value 0.98, and between lead V9 and the LA recording with a value of 0.93, $p < 0.00001$. Correlation was lower between V9 and RA, 0.69, and even lower between V1 and LA, 0.64, $p < 0.00001$.

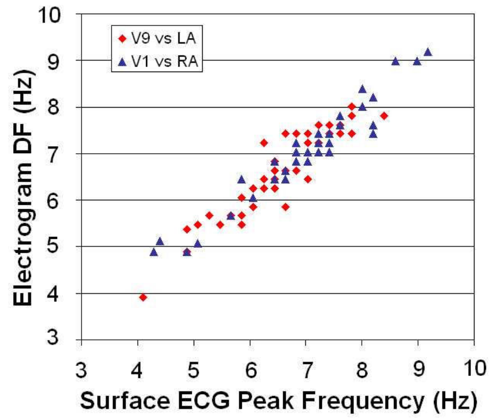

Figure 3. Peak frequency from ECG leads vs corresponding DF from intra-atrial electrograms recorded at the closest site.

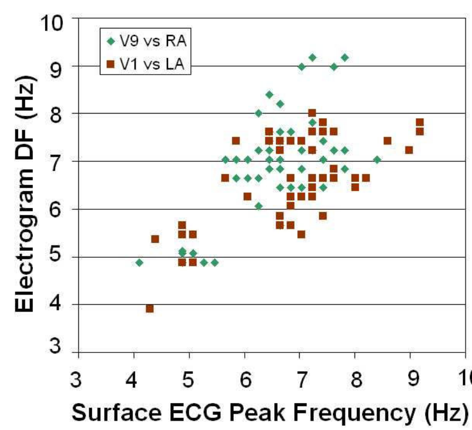

Figure 4. Peak frequency from ECG leads vs corresponding DF from intra-atrial electrograms recorded at a distant site.

Figures 3 and 4 show the peak frequency in the surface ECG plotted against the DF in the intra-atrial electrograms for all 51 5-second segments. We observe that there is a strong relationship between the surface ECG peak frequency and the intra-atrial recording DF when the two are close in location, as illustrated in Figure 3. Specifically, V9 has a close correlation with local left atrial events. When recording from locations that are far away from each other, the agreement between the two measurements decreases as shown by the larger scatter of data in Figure 4.

The mean absolute value frequency difference between V9 and LA was 0.23 Hz and between V1 and RA was 0.14 Hz. When the locations were far away from each other, the mean absolute value differences increased, V9 to RA was 0.74 Hz and V1 to LA was 0.81 Hz. This is illustrated in Figure 5.

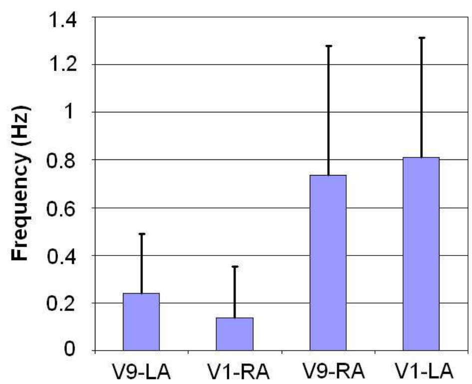

Figure 5. Mean absolute value frequency difference between local intra-atrial electrograms and surface ECG leads

Peak MSC values between V1 and RA ranged from 0.1 to 0.9, between V9 and LA from 0.1 to 0.5, between V9 and RA from 0.1 to 0.5 and between V1 and LA from 0.1 to 0.5.

4. Discussion and conclusions

It has been shown in recent studies that a gradient of frequencies between the left and right atria may exist in patients with AF [3]. These gradients play an important role in identifying the mechanisms of AF in different patients and help in identifying possible ablation targets [4].

Magnitude-Squared Coherence analysis showed that during AF there are moments of extremely high linearity between ECG recordings and local electrograms. This phase consistency can change over time and vary from patient to patient. This method may allow us to monitor changes in the atria during AF and possibly identify the firing foci initiating AF.

We were able to characterize local events from the surface ECG using simultaneous intra-atrial recordings as the gold standard. This demonstrates that lead V1 reflects mostly right atrial activity, while lead V9 reflects mostly left atrial activity. The infrequently used posterior leads seem to better reflect left atrial events than the standard 12-leads currently used in clinical practice.

Acknowledgements

The authors thank Dr. J. Nazari, M. Steffen RN, E. Garnier, P. Stokes and K. Carroll for their assistance with this project. This work was supported in part by a grant from The Dr. Scholl Foundation.

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