Contributions for the Optimal Lead Placement for the Study of Atrial Fibrillation Applying Independent Component Analysis to 64 Body Surface Potential Mapping Recordings

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Abstract

The interest in the study and analysis of Atrial Fibrillation has increased significantly in the last decades. A correct estimation of the atrial activity is a crucial previous step for AF analysis. Different methods based on Independent Component Analysis of 12-lead ECG have been proposed. However, they don't work for a reduced number of leads. The purpose of this study was (1) search of new spatial information of atrial fibrillation waves by means of multi-lead recordings and (2) to quantify the contribution of the estimated Atrial Activity (AA) on each lead in order to identify the optimal lead placement for successful extraction. Principal Component Analysis and second order blind identification methods were applied for AA estimation and identification. Contribution of each lead was assessed. A reduced set of leads which allows AA extraction was identified, located (1) to right of V1 and (2) below the left precordial zone.

1. Introduction

The electrocardiographic leads that Einthoven proposed a hundred years ago, are still the most widely used technique for non-invasive diagnosis in clinical practice. The location of the conventional leads is optimized for the recording of ventricular activity. However, definition of new lead sets that optimize the recording of atrial activity would be of great interest for those research studies that are focused in optimizing the diagnosis of atrial arrhythmias.

With this objective of a better caracterization and detection of the P-wave, different lead configurations have been proposed, such as the lead known as Lewis lead. Performance of this lead, compared to the standard leads has been reported in previous studies [1]. Other studies have performed a more systematic search for the optimization of the lead set that better records atrial activity in sinus rhythm [2-3].

The interest about the study and analysis of Atrial Fibrillation (AF) has been increased significantly in the last decades: better diagnoses, antiarrhythmic drug responses [4], prediction of AF termination [5], etc. The fibrillatory waves (f waves) are usually more visible in leads V1 and V2. Lead V1 is it the most commonly used for atrial activity (AA) estimation & characterization. More recently, new methods based on statistical analysis of the multidimensional signals (12-lead ECG) have been proposed for a global AA estimation from the set of the 12 leads and not only V1. A powerful separation algorithm adapted to the atrial activity estimation problem has been reported in [6].

It is of great interest to find new lead configuration systems aimed at extracting more information about atrial activity. Modified 12-lead ECG configurations have been suggested recently by [7] and [8], in which both precordial leads V1 and V2 were included. Ihara et al. [7] proposed a 2x3 grid on the upper right chest, which was placed in the region closer to the atria. In this study, this new placements were obtained by rearranging the conventional leads V3 to V6. Its performance was tested by applying it to ECG signals during AF, simulated by means of a biophysical model of human atria and thorax. The evaluation was carried out by singular value decomposition and entropy of singular value spectra. Husser et al. [8] also suggested four new electrode locations of conventional V3 to V6 electrodes. They were empirically repositioned anterior or posterior over the atria in order to improve an individual characterization of the fibrillatory process. Its performance was tested in 19 patients with persistent AF and a time-frequency analysis was applied. In both cases, the results indicate that the new lead system provides more information on the atrial electrical activity than the standard 12-lead ECG configuration.

Our study is focused on the definition of a new lead set optimized for the study of atrial activity. With this purpose, we departed from a 64-lead Body Surface Potential Mapping System and applied Independent

Component Analysis (ICA), without prior knowledge about the leads that should be considered as optima.

2. Methods

2.1. Body surface potential mapping recordings

The system used to record electrocardiographic signals has been previously described [9]. Briefly, electrocardiographic signals are sampled at 2048 Hz with an amplitude resolution of 1μV/bit. Time intervals lasting 2 minutes were stored on hard disk by means of a computer for its later processing. The bandwidth of the system is 512 Hz, which is enough for high-frequency QRS analysis.

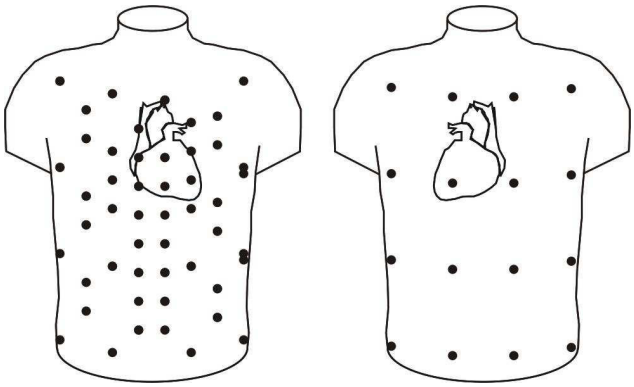

Figure 1: BSPM electrodes configuration. Position of the electrodes are marked by dots. Left panel: chest. Right panel:back.

Electrodes are distributed non-uniformly upon the chest: a set of 16 electrodes are placed uniformly in the back and the rest non-uniformly in the anterior side, with a highest density at positions overlaying the heart. Electrode positions can be observed in Figure 1. Electrodes are mounted on an elastic vest designed by our group to be attached fast and easily to the patient's body.

Five patients with persistent AF were enrolled in the study. All of them were men (100%) admitted in the electrophysiology Laboratory of Hospital Clínico Universitario de Valencia (HCUV) for cardioversion protocol (CVD).

2.2. Atrial activity estimation

A basic preprocessing was carried out to eliminate DC and base line fluctuations. A whitening process based on Principal Component Analysis (PCA) was applied to reduce the dimension of the problem from 64 to 8. Since the 12-lead ECG contains at most 8 independent signal components. After that, a Second Order Blind Identification (SOBI) algorithm was applied to find the unmixing matrix that diagonalizes the cross-correlation matrix of whitened observations at several lags simultaneously [10].

Once 8 sources are estimated (Fig.2-3), the next step involves the identification of AA by means of spectral features and statistical information. Theoretically, a narrow band around a main frequency peak (fp), typically located between 5Hz & 10 Hz, and a low value of kurtosis (K<1). We suggested the identification of only one estimated source as AA, defined as the estimated source which better accomplish these criteria.

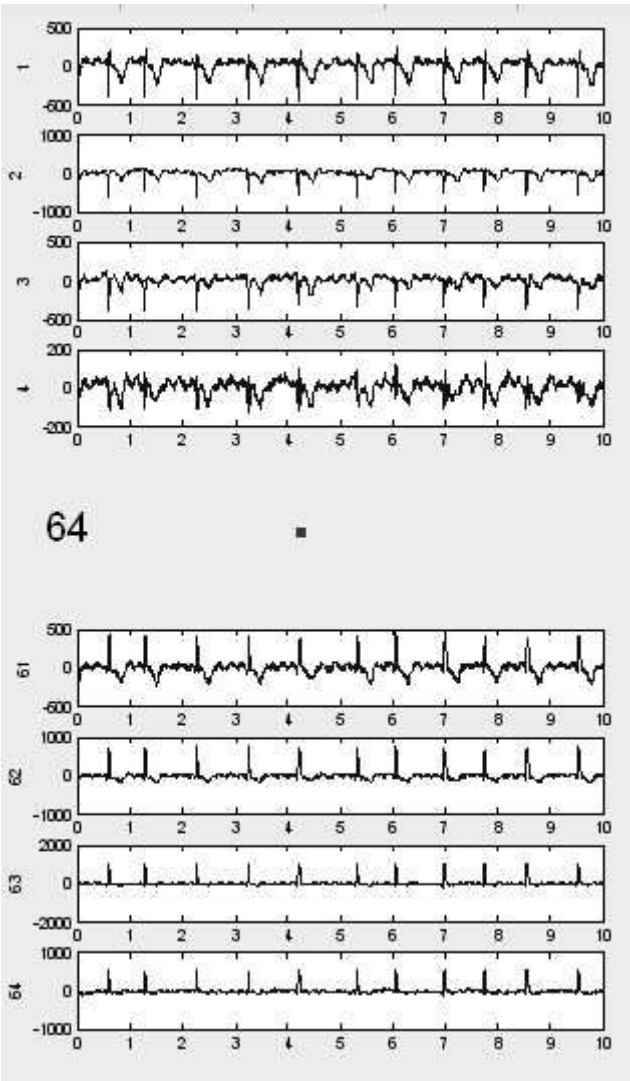

Figure 2: 64 recorded leads of one patient from BSPM system.

2.3. Optimal leads identification

By analysing the entries of the row of the unnmixing matrix that can be used to extract the AA estimated source and the corresponding column of the estimated mixing matrix (the pseudoinverse of the unmixing one), the contribution of the AA in each lead could be quantified. These values are plotted in a 2-D code by colours for each lead, Fig.4.

Finally, mean and standard deviation of the following parameters are reported: main frecuency peak (fp), Kurtosis (K) and Spectral concentration in the expected band (SCeb) defined from 4Hz to 10 Hz vs full spectrum.

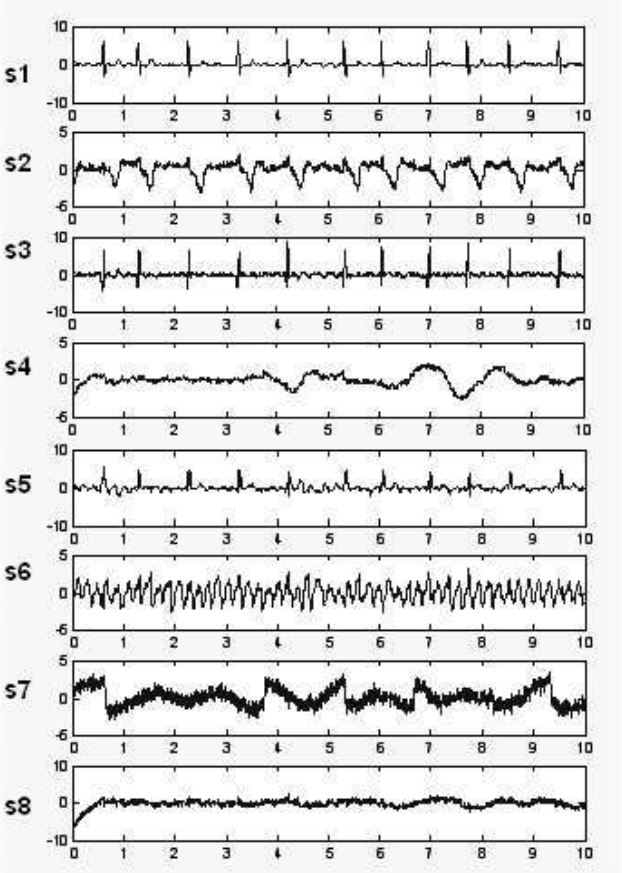

Figure 3: Estimated sources (s1 to s8) after applying PCA to original 64 recorded leads from the same patient.

3. Results and discussion

Fig. 2-3 illustrates the methodology described above applied to one patient. In this case, by simple visual inspection it is easy to notice that 's6' is a strong candidate to be selected as AA estimated source. A main frequency peak of 4.75 Hz, SCeb = 0.85 and K= -1.16 corroborate this suspicion. For the same patient, Fig 4 shows the spatial contribution of each lead for the estimated source AA. Leads located at the right of lead V1 and below the left precordial zone are the most significant. Even in this case with only 2 leads it is possible to extract the AA with a good performance, see Fig.4.

The behaviour (average ± standard deviation) of the 3 defined parameters is summarized in Table 1.

Table 1. Main parameters of the signals

Main frequency peak (fp)	5.5 ± 1.2 Hz
Kurtosis (k)	- 0.21± 0.71
SCeb	0.65 ± 0.13

Finally, in some cases it is present some residuum corresponding to atrial activity in other sources different that the source identificated as AA ('s6'). Although in this case the residuum is not important, there are cases in which the residuum is noticeable. This fact raises the question of whether the reduction of 64 leads into 8 sources is excessive. Also, another fact that can influence the appearance of peaks in different frequencies can be due to the contribution of both atria, different mechanisms, etc.. Anyways, the condition imposed of estimating only one AA allows us to center the problem in the most dominant frequency.

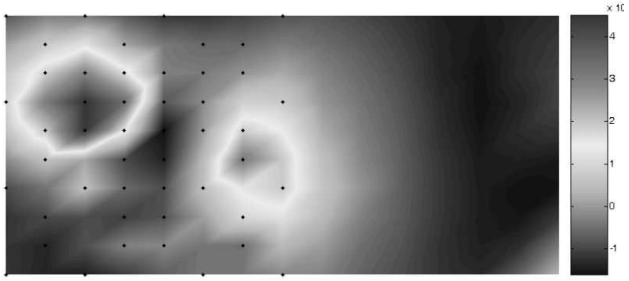

Figure 4: Contribution of the AA estimated source on each lead.

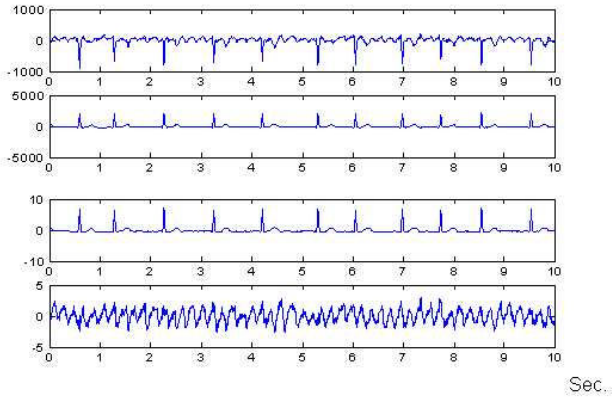

Figure 5: AA and VA (4th and 3rd signals) estimated

from 2 surface ECG leads (1st and 2º signals).

4. Conclusions

A systematic study based on BSPM recordings and ICA methods without a prior knowledge has been proposed for optimal lead placement for the study of atrial fibrillation.

The application of this methodology to a reduced number of patients with persistent AF allows to do the following preliminary conclusions:

Leads V1 and V2, as expected, are among the optimal ones. But, they are not the best ones.

None of the back leads are among the optimal ones. This result is unexpected a priori.

In one patient, with only two leads are enough for better AA estimation. This is a great discovery for Holter analysis. Combinations of 3-4 leads were also found for the other patients with a fine performance.

Future works need to be analysis this conclusions in depth with a greater number of cases.

Acknowledgements

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References

[1] Madias JE. Comparison of P waves recorded on the standard electrocardiogram, the "Lewis lead," and "saline-filled central venous catheter"-based intracardiac electrocardiogram. Am J Cardiol. 2004; 94(4): 474-8

[2] Lux RL, Greg R. New Leads for P wave detection and arrhythmia classification. Journal of Electrocardiology 2004; 37: 80

[3] Climent A. et al. Optimal lead selection for the study of the P wave in sinus rhythm. Computers in Cardiology. 2005; 32,195-8

[4] Fujiki A et al. Usefulness and safety of bepridil in converting persistent atrial fibrillation to sinus rhythm. Am J Cardiolo. 2003;92:472-5

[5] Bollmann A, Husser D, Stridh M, et al. Frequency measures obtained from the surface electrocardiogram in atrial fibrillation research and clinical decisión-making. J Cardiovasc Electrophysiology. 2003;14:S154-61.

[6] F Castells, JJ Rieta, J Millet, V Zarzoso. Spatiotemporal blind source separation approach to atrial activity estimation in atrial tachyarrhythmias. IEEE Trans on Biomed Eng. 52 (2005) 258-67.

[7] Z Ihara et al. Adaptation of the Standard 12-lead ECG system focusing on Atrial Electrical activity. Computers in cardiology. 2005; 32,205-8.

[8] D. Husser et al. Electroatriography-Time-Frequency Analysis of AF from Modified 12-lead ECG Configurations for Improved Diagnosis and therapy. Medical hypotheses (in press)

[9] Guillem, M. S., Millet, J., Bodí, V., Mora, C., and Chorro, F. J. Integration of a Body Surface Potential Mapping System. X Mediterranean Conference on Medical and Biological Engineering. 2004.

[10] R Llinares, J Igual, J Millet, M Guillem. Independent component analysis of body surface potential mapping recordings with atrial fibrillation. International Joint conference on Neural networks, 2006; 4595-4601.

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