Algorithms for Atrial Signal Extraction in Atrial Fibrillation ECGs: A Comparison Based on the Correlation Between Endocardial and Surface Dominant Frequency

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Background

The non-invasive analysis of atrial fibrillation (AF) from ECG recordings relies on the separation of ventricular activity (VA) from atrial activity (AA).

- Approaches to AA extraction:
  - ◊ Average beat subtraction (ABS): single and multi-lead [1-3]
  - ◊ Blind source separation (BSS): principal and independent component analysis (PCA, ICA) [4,5]
- The comparison of the different approaches has already been performed:
  - ◊ In time and frequency domains: comparison of f-wave amplitudes and AF dominant frequencies (AFDFs) [6], spectral concentration (SC) [7]
  - ◊ Only ECG-based criteria, need for validation

OUR GOAL: Assessing the performance of three AA extracting approaches based on the correlation between surface and endocardial AFDF.

Results obtained with the proposed criterion are compared with those obtained from an ECG-based quality index (SC).

AA extraction methods under comparison

Single-lead ABS

Adaptive Singular Value Cancelation (ASVC) [1]

- Lead V1
- Singular value decomposition of the N=24 beats correlating best with the current beat
- Principal component taken as best QRST estimate

Multi-lead ABS

Bayesian Spatio-Temporal Cancelation(BSTC) [3]

- Data model for each beat x_i of lead j:

$$x_{ij}=\mathbf{H}\Theta_{ij}+a_{ij}$$

- The optimal linear combination Θ_{ij} is the one corresponding to the weighted least square estimation of the "spatial" ventricular template $\mathbf{H}$, assuming a_{ij} correlation structure is known
- Lead V1 residual retained for further analysis

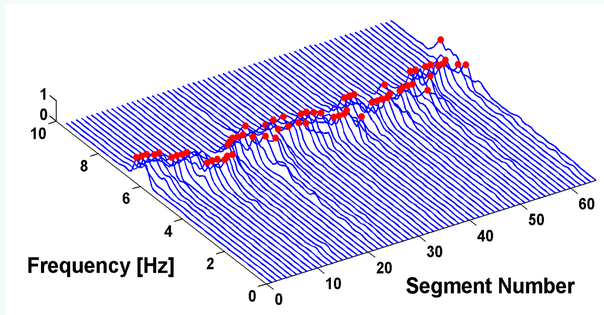
Blind Source Separation

RobustICA-f [4]

- ICA performed segment-wise in the frequency domain after pre-whitening in time domain
- Segment length: 8 s, overlap size: 7 s
- Best AA estimate: source with AFDF Є [3,9] Hz and highest SC

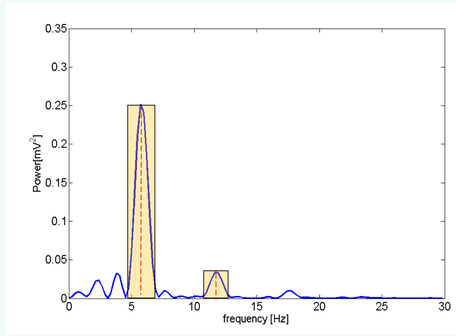
Methods

- **Database:**
  - ◊ 20 patients (pts, 19 males, 60±11 y)
  - ◊ Persistent AF. Episode duration: median 4.5 months, 4 to 19
  - ◊ 12-lead ECG + simultaneous left atrial appendage endocardial recording (LAA EGM)
- **ECG AFDF estimation:**
  - ◊ Short-time Fourier transform: time-frequency study of the AA from ECG after ICA and preprocessed LAA EGM
  - ◊ Segment length: 8 s
  - ◊ Overlap size: 7 s
  - ◊ Median as best AFDF estimate



- **EGM/ECG AFDF correlation**: Linear regression analysis and Pearson's correlation coefficient R
- **SC index:**

$$\mathrm{SC}=\sum_{k=1}^{2}\frac{\sum_{0.82kf_p}^{1.17kf_p}P_{AA}(f)}{\sum_{0}^{f_s/2}P_{AA}(f)}$$



Statistical analysis: one-way ANOVA and a multiple comparison test to determine differences in parameters' distribution means

Results

- Non-significant difference between ECG AFDF computed with the three methods under comparison and EGM AFDF (Fig. 1)
- SC is significantly higher for AFDF computed with RobustICA-f ($P<10^{-8}$). See Fig. 2
- R is significant only when RobustICA-f is employed (Fig. 3)

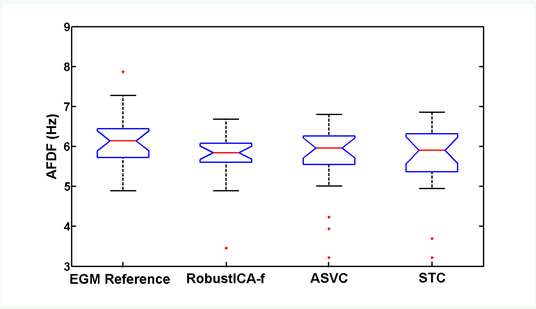


Fig. 1: Box-and-whiskers plot of the EGM AFDF (reference) and the ECG AFDF for the different methods.

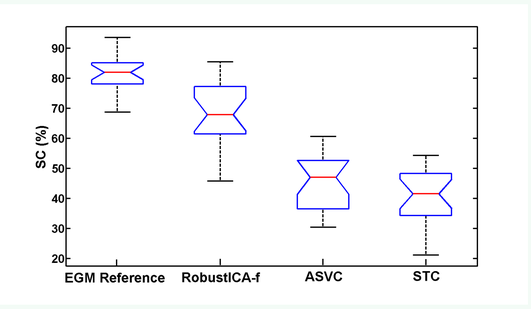


Fig. 2: ECG/EGM AFDF correlation after AA extraction using RobustICA-f (left), ASVC (center), STC (right).

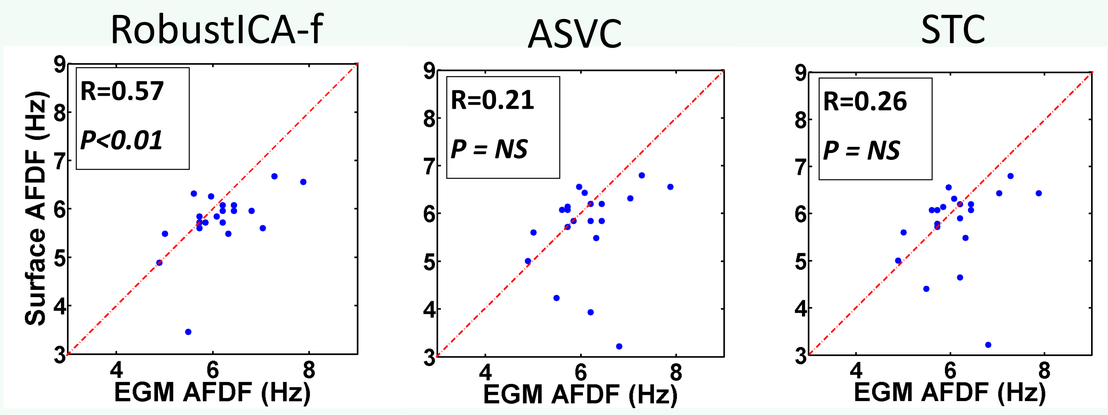


Fig. 3: ECG/EGM AFDF correlation after AA extraction using RobustICA-f (left), ASVC (center), STC (right).

Conclusions

- Comparison of three methods for non-invasive AA extraction
- New separation performance assessment criterion based on the EGM/ECG AFDF correlation R
- The proposed criterion is compared to an ECG-based criterion, the SC index
- The BSS based approach offers the best performance both in terms of EGM/ECG AFDF correlation and SC index value
- The correlation-based criterion appears to validate the ECG-only based criterion SC.

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