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).**

**Methods**

**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 $x_t$ of lead $j$: $x_t = H_t + a_{ij}$
  - The optimal linear combination $\Theta$ is the one corresponding to the weighted least square estimation of the “spatial” ventricular template $H$, 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 $\in [3,9]$ Hz and highest SC

**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)

**ECC 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:**

\[
SC = \sum_{k=1}^{2} \left[ \frac{1.172}{0.923} \frac{T_k}{T_{2}} \right] PAA(f) J
\]

**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 ($P<10^{-6}$). See Fig. 2
- $R$ is significant only when RobustICA-f is employed (Fig. 3)

**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.

**REFERENCES**

5. O. Meste and N. Serfaty. QRST cancellation using bayesian estimation for the auricular fibrillation analysis.
7. 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]

**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), BSTC (right).

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