QRS-T pattern subtraction in unipolar atrial fibrillation electrograms

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Introduction

- Atrial and ventricular frequency contents overlap;

- Ventricular activity often has larger amplitude than atrial activity;
Atrial Fibrillation:

Increase AF frequency activation
Contribute to the unbalanced and complex propagation.

As consequence, intracardiac electrogram presents different morphologies related with the structure conduction disturbances of the atrium.

These disturbances, subsequently, affect the external ECG of AF patients where the P waves are replaced by f waves presented over the baseline.
Introduction

During Atrial Fibrillation:
Average Beat Subtraction (ABS)  
Slocum et al 1985, Circulation  
- Relies on the fact that AF is uncoupled to ventricular activity  
- Single Lead Approach (II or V1)  
- Subtraction of the MEAN BEAT  
- Mean RR interval (Fiducial point in the middle)  

Blind Source Separation (BSS)  

Principal Component Analysis (PCA)  
Langley et al 2000. CinC  
- QRST subtraction  
- 12 Leads Approach  
- PCA reduces the number of variables when the variables are non-independent  
- 12 Orthogonal data components  
- It lends itself well to 12-lead ECG analysis since all electrodes measure the same source of electrical activity (the heart) and leads are not independent  
- Select the Orthogonal Component most related to the atrial activity  

Independent Component Analysis (ICA)  
Rieta et al 2004. IEEE Transactions on BME  
- QRST subtraction  
- Single lead approach (II)  
- Recovering a set of source signals from the observation of linear mixtures  
- Nothing is known about the source signals or the mixing structure (hypothesis of source mutual independence)  
- Being \( x(t) \) the M sensor output vector and \( s(t) \) the vector representing the N source signals, the ICA model reads: \( x(t) = As(t) \)  
- The aim is to estimate \( s(t) \) and \( A \) from the exclusive knowledge of \( x(t) \).  

Adaptive Ventricular Cancellation  
Rieta et al 2007  
- QRST subtraction, Noise Cancellation and Arrhythmia Detection  
- Single Lead Approach (II)  
- External ECG (Ref Signal Channel) and the Internal Atrial Signal (Main Signal Channel)  
- Error between Filter Output and Intracardiac Signal is used to adjust the filter coefficients by minimizing the Mean Square Error (MSE)
Spatiotemporal QRST Cancellation Techniques

Standard Spatiotemporal
Stridh and Sornmo, 2001, IEEE Trans. on BME

Separate QRS and T-Waves Templates
Lemay et al. 2005, CinC

- 12 Leads Approach
- Purpose of separating morphologic beat-to-beat variability from respiratory-induced variations
- Cross correlation-based beat classification and a beat average is computed for each of the classes
- Correction of each template $T_k$ by a diagonal amplitude scaling matrix $D$ and a rotation matrix $Q$.

- Single lead approach
- After QRS detection, it was replaced by either flat, linear or spline interpolation.
- The subtracted points were 41.67 ms before and 50 ms after the detection.

Flat, linear and spline interpolations
A. Ahmad et al., 2011 Med Biol. Eng. & Comp.
Methods

**Average Beat Subtraction (ABS)**
Slocum *et al.* 1985,
*Circulation*

- Relies on the fact that AF is uncoupled to ventricular activity
- QTST subtraction
- Single Lead Approach (II or V1)
- Subtraction of the MEAN BEAT
- Mean RR interval (Fiducial point in the middle)

**Flat, linear and spline interpolations**
A. Ahmad *et al.*, 2011

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- The subtracted points were 41.67 ms before and 50 ms after the detection.

**QRS Segmentation**
JP Madeiro *et al.*, 2011
+ T Wave Seg
Not validated yet
+ T distortion
Not validated yet
(Madeiro & Schlindwein)

- QRS onset and offset
- R-R Peaks
- T wave end
- QTST segment

![Graph](image)
Aim

The objective of this study was to remove ventricular activity from the intracardiac AF electrograms to obtain a valid frequency domain characterization (Dominant Frequency Analysis).
Noncontact Mapping Technique

Multi-electrode Array (Noncontact):
- Array of 64 braided electrodes.

Ensite Array System:
- Inverse solution to Laplace’s equation to ascertain how a signal detected would appear on the endocardial surface;
- Summation from all electrodes to generate the potentials from a single site;
- 3,360 virtual electrograms are produced;
- Electrograms are represented into a 3D of the cardiac chamber in an isopotential mode.
- Intracardiac signals were simultaneously recorded with the ECG
Methods

Fig. 1 General Block diagram from the proposed QRS-T subtraction method
Methods

Pre-processing

External ECG with Noise (Notch Filter)
Pre-processing

Baseline Wandering: cubic spline interpolation anchored on the onset points of ventricular depolarization: CinC 2005, Lemay

Methods

Fig. 1 General Block diagram from the proposed QRS-T subtraction method

- ECG signal
- QRS detection/segmentation and T-wave end location
- Computing of the QT pattern in the intracardiac signal
- Subtraction of the QRS-T segments
- Computing of the delay
QRS-T Segmentation


Methods

Fig. 1 General Block diagram from the proposed QRS-T subtraction method
Methods - Alignment via correlation

Before Alignment

After Alignment
QRS-T subtraction in AF Signals

ECG

Intracardiac

Atrial Electrogram
3 techniques compared
Results

[Image of heart diagram showing anatomical structures like Aorta, Pulmonary Artery, Pulmonary Vein, Left Atrium, Mitral Valve, Right Atrium, Tricuspid Valve, Right Ventricle, and Inferior Vena Cava.

Graphs showing frequency spectrum with labels "Raw" and "QRST-Segmentation".

Mesh representation of a heart with labeled regions: RUPV, LUPV, LLPV, Roof, Septum, Mitral Valve.

Legend with colors and labels for different regions of the heart mesh.]
Results

[Heart diagram showing important structures such as Superior Vena Cava, Aorta, Pulmonary Artery, Left Atrium, Mitral Valve, Left Ventricle, and more.]

[3D mesh model of the heart with labeled areas such as RUPV, Roof, LUPV, and LLPV.]

[Graph showing frequency (Hz) on the x-axis and Power on the y-axis, with two peaks close to Mitral Valve.]
Results
Measuring improvement

\[ P_{ratio} = \frac{P_{5.5-12}}{P_{3-5.5}} = \frac{\int_{5.5}^{12} P(f) df}{\int_{3}^{5.5} P(f) df} \]

Ratio between the frequency components in the range [5.5-12 Hz] and [3-5.5 Hz] for each QRS-T subtraction approach and each atrial region.

<table>
<thead>
<tr>
<th></th>
<th>Mitral Valve</th>
<th>Pulmonary Veins</th>
<th>Roof</th>
<th>Septum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>1.04</td>
<td>1.60</td>
<td>3.39</td>
<td>1.96</td>
</tr>
<tr>
<td>QRS</td>
<td>0.85</td>
<td>1.46</td>
<td>3.05</td>
<td>1.86</td>
</tr>
<tr>
<td>QRS-T-ABS</td>
<td>2.45</td>
<td>3.38</td>
<td>5.07</td>
<td>3.71</td>
</tr>
<tr>
<td>QRS-T-Seg</td>
<td>2.41</td>
<td>3.26</td>
<td>5.33</td>
<td>3.76</td>
</tr>
</tbody>
</table>
Conclusions

- This research proposes an approach for QRS-T subtraction in atrial fibrillation unipolar intracardiac electrograms.

- QRS onset detection and T-wave end location for further computing of QRS-T patterns related to intracardiac signal segments.

- Frequencies above 10 Hz were well attenuated for both the roof and mitral valve areas

- The effect of ventricular repolarisation (T-wave) is directly related with the frequency content between 3 Hz to 5.5 Hz
The Team

Engineering

- Anita Ahmad, Federico Rocha, Taher Biala, João Salinet, Joseph Ahuja, Cath Taylor, Tang Bo, Wajid Aziz, Alexandre Lobo, João Madeiro, Paulo Cortez, Frederique Vanheusden, Tiago de Almeida, Xin Li, Nawshin Dastagir, **Fernando Schlindwein**

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- Peter Stafford, Gerry McCann, Will Nicolson, Peter Brown, Shamil Yusuf, Mathew Smith, Jiun Tuan, Alastair Sandilands, Sharon Man, Subrahmanya Varanasi, Sam Trethewey, Shoaib Siddiqui, Gavin Chu, **André Ng**

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QRS Segmentation

1. Wavelet Transform: $x(n) = W_{a}[ECG(n)]$
2. Scale Factor: $2^a$
3. $y(n) = \frac{d}{dt}[x(n)]$
4. $V(n) = |h(n)|^2 + |y(n)|^2$
5. Hilbert Transform: $h(n) = H[y(n)]$