Analysis of P-wave Changes for Prediction of Atrial Fibrillation Episodes

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Purpose:

Atrial Fibrillation (AF) is the most prevalent arrhythmia in clinical practice, increasing the risk of stroke and all cause mortality[1]. It usually initiates as a paroxysmal activity (PxAF), with the subject having sinus rhythm (SR), with interleaved AF episodes.

There are several studies [2,3] which point out that P-wave morphology can be a noninvasive marker of predisposition to AF. Specifically, in [2], it was hypothesized that slower conduction in the atria and the presence of fibrosis in the atrial myocardium, both associated to AF, lead to P waves widened, more complex and with increased rugosity.

Aim: To assess changes in **P-wave morphological features in sinus rhythm: duration, power and power at high frequency bands**, as predictors of AF episodes in the minutes previous to its ocurrence, in patients with PxAF.

Data & Methods:

ECG recordings [4] **from subjects with PxAF** recorded at State University of St. Petersburg (Russia).

- **35 ambulatory** (1 - to -7 day) **Holter** recordings with an average duration of 104 hours (range: 21-156 hours)
  - **Four 12-leads recordings**: fs = 250 Hz
  - **Thirty-one 3-leads recordings:** fs = 257 Hz
- **Annotation of AF episodes** [4] based on fuzzy logic [5], involving information on ventricular rhythm [6], atrial rhythm, f-wave morphology and noise.

ECG signal → **Pre-processing** ➤ Baseline wander and muscle noise band pass filtering (Fc from 0.5 to 50 Hz).

ECG segmentation ➤ **205** excerpts **of 5 min duration**, taken at **60, 30 and 5 min before** each **AF episode**

P-wave extraction ➤ **Beats are extracted and aligned with respect to the QRS fiducial point**. ➤ From each k-th beat of each l-th lead we segmented a time window of 160 ms, starting 220 ms before the QRS mark.

PCA — Maximizes the energy of the P-wave
πCA — Maximizes m-beat periodic structure (m=1)

➤ Linear spatial transformations, **Analysis of Principal Components (PCA)** and **Analysis of Periodic Components (πCA)** aiming at improving the SNR by exploiting spatial redundancy in multilead ECGs.

Beat averaging ➤ Compute the average beat of each of the first three principal/periodic components.

Morphological P-wave features
➤ Power of the i-th transformed component, $\mathcal{P}_i^\Psi$ where $\Psi \epsilon \{PCA, \pi CA\}$ and $i \epsilon \{1,2,3\}$
➤ Relative Power of the second-to-first component, $\mathcal{P}_2^{\Psi,r} = \mathcal{P}_2^\Psi / \mathcal{P}_1^\Psi$
➤ Relative power of third to-first plus second component, $\mathcal{P}_3^{\Psi,r} = \mathcal{P}_3^\Psi / (\mathcal{P}_1^\Psi + \mathcal{P}_2^\Psi)$
➤ Power of the P-wave after HPF Fc = 30 Hz, $\mathcal{P}_1^{\Psi,HF}$ (as a measure of rugosity)
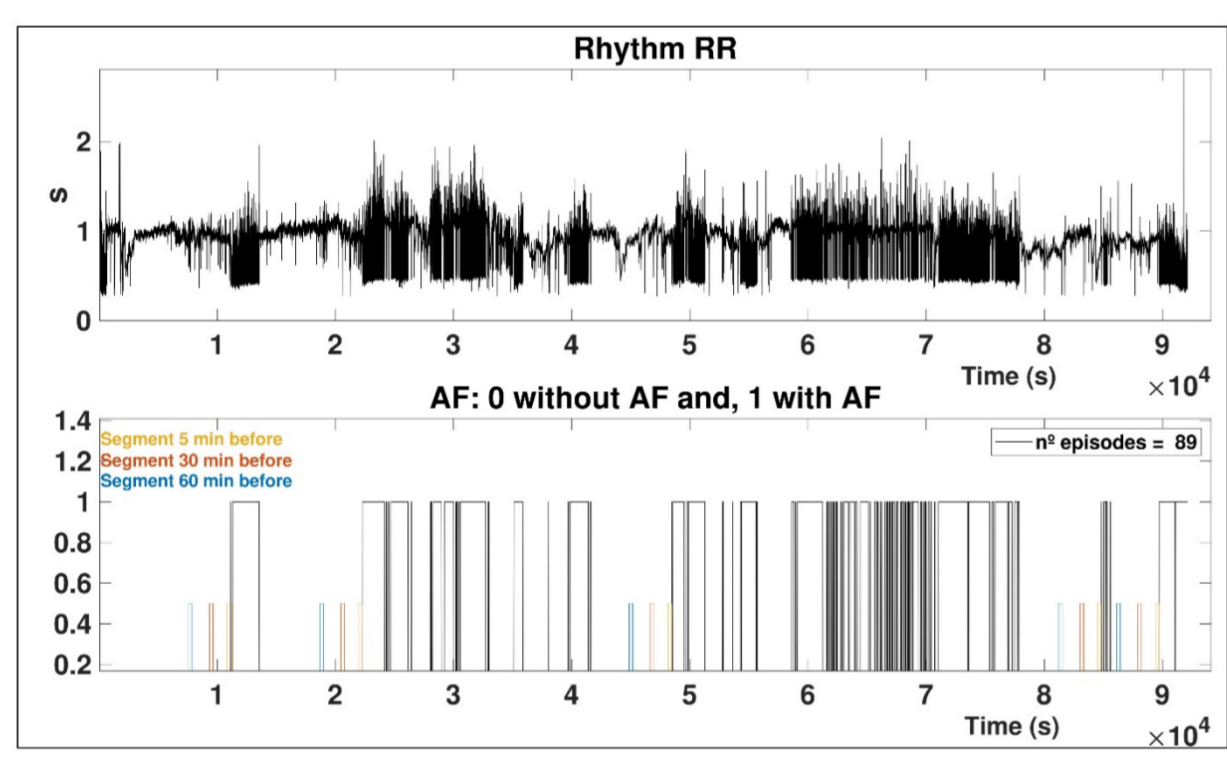➤ P wave mean duration D_m^Ψ of the first averaged PCA and πCA [6].

Figure 1. RR in a recording from the dataset (top) and selected AF episodes with preceding analyzed excerpts at SR (bottom)
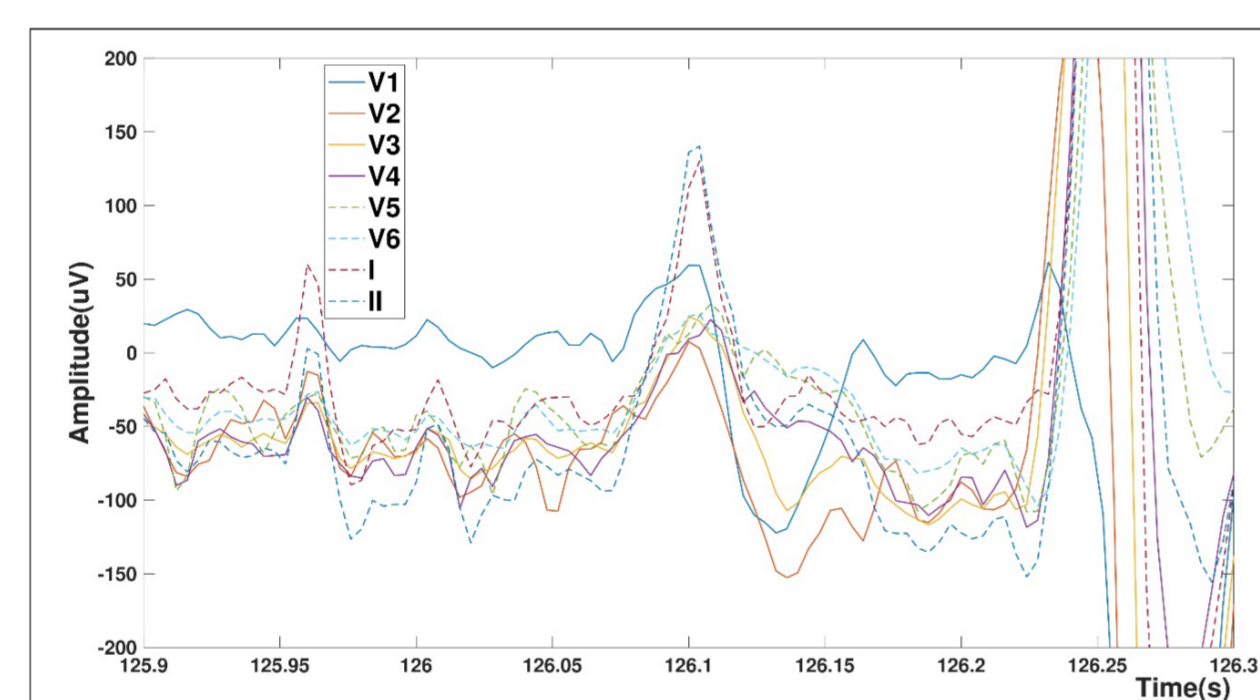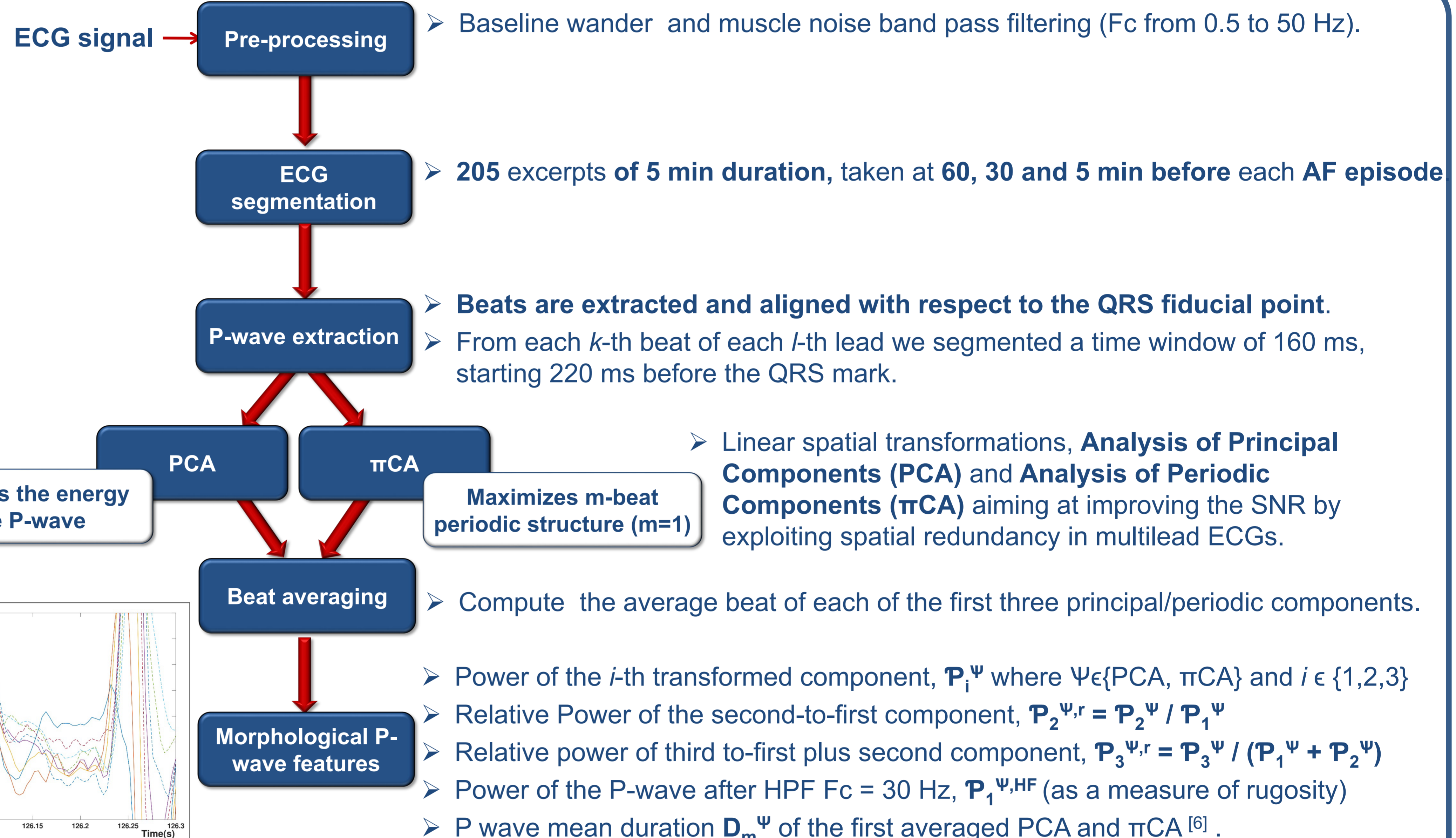
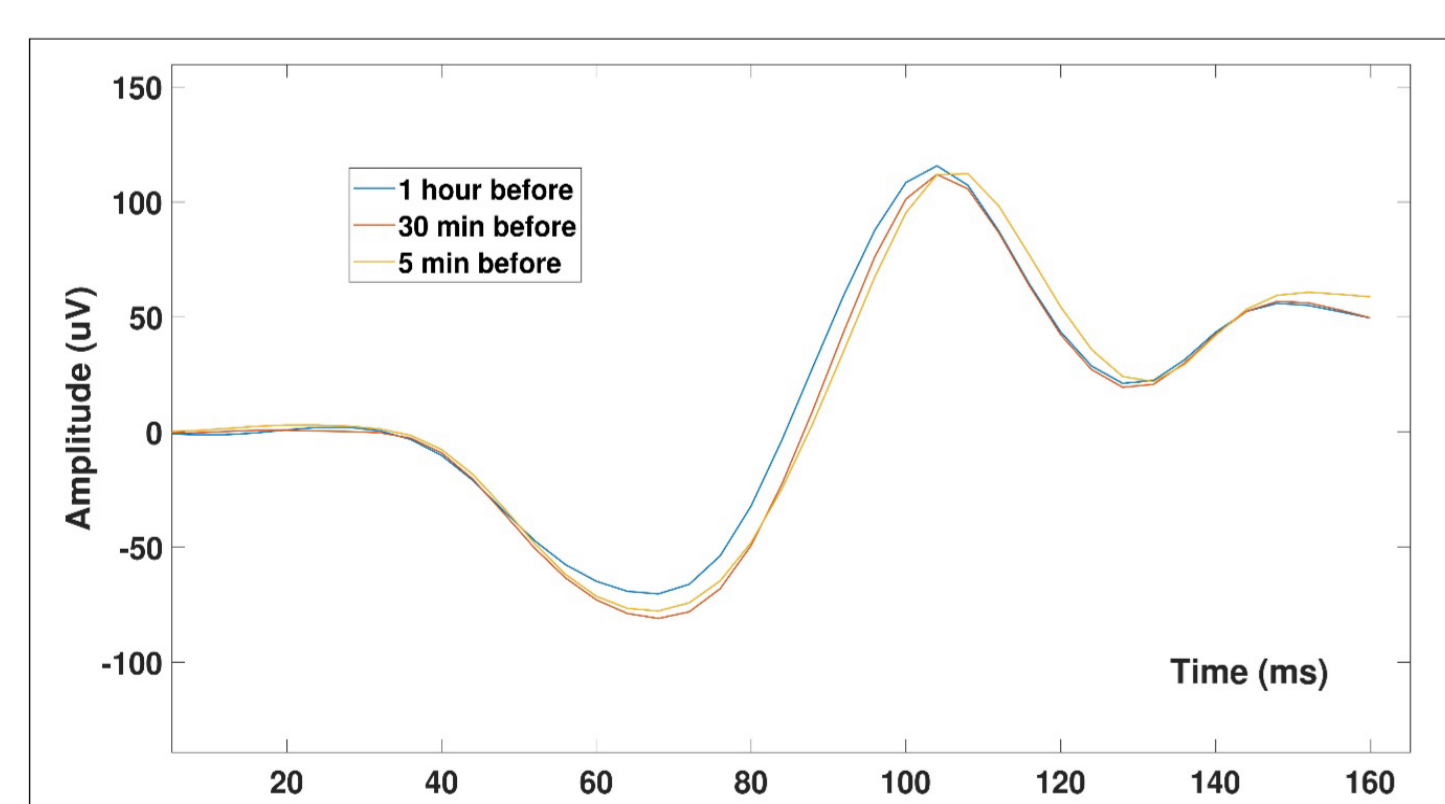Figure 2. P-wave Register #1, 60 min before an AF episode

Results:

Figure 3. Temporal evolution in the minutes previous to the first PxAF event in record #1, of the averaged P wave beat at the second PCA lead.
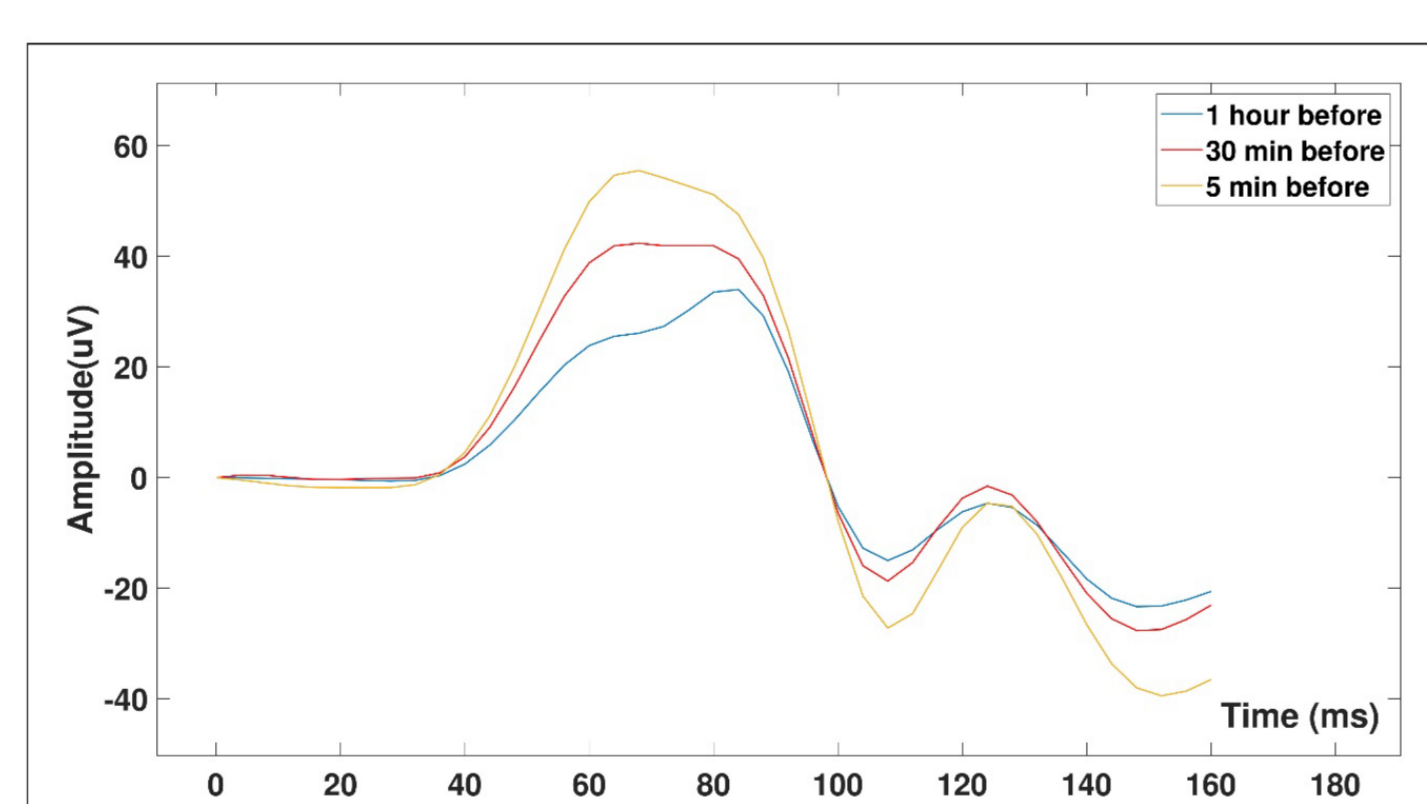
Figure 4. Temporal evolution in the minutes previous to the first PxAF event in record #1, of the averaged P wave beat at the second πCA lead.

✓ **Power and relative power:**

✓ $\mathcal{P}_2^{PCA}$ **increased** from 60 to 30 min (p=0.015)

✓ $\mathcal{P}_2^{PCA,r}$ **increased** from 60 to 30 min (p=0.006) and from 60 to 5 min (p=0.002).

AS AF APROACHES → MORE SPATIALLY COMPLEX LOOP

✓ No significant differences were found in the $\mathcal{P}_1^{\Psi,HF}$ by none of both methods.

✓ **Duration**: a significant increase was found in:

✓ D_m^{PCA} from 60 to 30 min (p=0.00022) and from 60 to 5 min (p = 0.00017).

✓ $D_m^{\pi CA}$ from 60 - 5 min (p=0.011).

AS AF APROACHES → SLOWING DOWN OF THE CONDUCTION MORE COMPLEX PROPAGATION

✓ No significant results were obtained when analyzing lead V1 (closest to the atria).

Feature	60 min	30 min	5 min
$\mathcal{P}_2^{PCA}$ (μV/samples^2)	45.3 [67.3]	47.3 [62.0]*	47.2 [71.5]
$\mathcal{P}_2^{PCA,r}$	0.129 [0.16]	0.142 [0.18]*	0.147 [0.26]*
D_m^{PCA} (ms)	112.8 [10.5]	116.7 [12.6]*	116.8 [22.9]*
$D_m^{\pi CA}$ (ms)	105.1 [31.1]	108.0 [31.1]	108.9 [31.1]*

Table 1. Features with present signficant evolution at the selectd time instant previous to PxAF events, Median [IQR] for PCA and πCA. Significant differences in italics and *p<0.016 vs 60 min

➤ Wilcoxon signed rank test and Bonferroni correction, to compare the features at the different times (significant level p ≤ 0.016).

[1] Laslett L. et al. J. Am. Coll. Cardiol. , 2012.
[2] Platonov P. ANE, 2012.
[3] Censi F. et al. Sci Rep May. ANE, 2016.
[4] Henriksson M., Martín-Yebra A. et al. IEEE Trans Biomed Eng, 2021.
[5] Petrènas A. et al. Med Biol Eng Comput, 2015.
[6] Martínez et al. IEEE Trans Biomed Eng, 2004.

Conclusions:

P-wave morphology significantly changes prior to the onset of AF episodes in PxAF making **more complex P-wave loop,** and enlarging its duration, which can be attributed to the destructuring of the atrial wavefront. These results should be further investigated in larger populations to corroborate the significance of the clinical markers as predictors to **AF** episodes.