Dynamic Changes in Episodes of Atrial Fibrillation as Predictors of Permanent Atrial Fibrillation Using Implantable Device

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Abstract

Pacemakers are effective in treating atrial fibrillation (AF) patients with bradycardia or atrioventricular block by restoring regular heart rhythms. High atrial rate episodes detected by cardiac implantable devices may indicate a risk of progression to long-duration AF episodes ($\geq$24 hours). This study analyzed five electrograms from 24 patients with implantable cardioverter defibrillators and pacemakers over 427 days, alongside their medical histories and daily activity records, to identify predictors of AF evolution. During the follow-up, 33% of patients experienced AF episodes lasting $\geq$24 hours. Longer AF episodes were linked to higher atrial rates, and greater signal irregularity. Continuous monitoring of atrial episodes may enhance decision-making and patient care in clinical settings.

1. Introduction

Atrial fibrillation (AF) is the most prevalent sustained cardiac rhythm disturbance among adults, affecting millions worldwide. It is characterized by disorganized atrial electrical activity that leads to irregular ventricular response. The prevalence of AF has increased significantly due to an aging population and the growing burden of cardiovascular risk factors [1]. Understanding the electrophysiological mechanisms underlying AF is crucial, as the duration of AF episodes is linked to increased risks of stroke and heart failure [2, 3]. This connection is further elucidated by theoretical concepts such as the "fibrotic substrate theory" suggest that structural alterations in the atrial myocardium, including fibrosis and dilation, may predispose patients to longer-lasting AF episodes [4].

On the other hand, the introduction of cardiac implantable electronic devices (CIEDs), such as pacemakers and implanted defibrillators, to treat patients that develop bradycardia or other rhythm disturbances have evolved into long-term continuous diagnostic tools [5, 6]. These devices have significantly enhanced our understanding of heart-rhythm disorders and their associated prognoses. Continuous electrical activity could offer valuable information about atrial and ventricular activity patterns, enabling us to gain deeper insights into the dynamics of AF.

In this way, advancements in technology CIDEs equipped, with high-density, low-power consumption memory that can automatically record and store episodes of spontaneous atrial tachyarrhythmias according to programmable detection criteria. Episodes, recorded as interval data, local electrograms, or both, have garnered attention as they may indicate nonsustained AF potential precursors to sustained AF.

This study aims to identify specific patterns in atrial and ventricular activity that could serve as predictive markers for prolonged AF episodes, particularly those extending beyond 24 hours from the onset. We aim to study AF through the lens of data provided by implantable devices and results could enhance risk stratification and guide clinical decision-making in managing AF patients.

2. Materials

The study included 24 patients with a history of paroxysmal AF, consisting of 7 women and 17 men. The patients were monitored over a follow-up period of 427 days, providing a comprehensive evaluation of the progression of the arrhythmia.

For each patient, we recorded several key parameters throughout the studied period, including clinical parameters such as age and sex. (Table 1). Additionally, we tracked various activity metrics, including average daily activity in hours, average and maximum atrial activity

(AA) during both the day and night, and the presence of AF episodes and their respective durations.

Table 1. Characteristics of Participants.

	Gender	
	Women	Men
Participants	7	17
Age	76.8±7.7	71.3±12.8
Overweight	5 (71,4%)	7 (41,2%)
Long-lasting AF events (¿24h)	3 (37,5%)	5(29,4%)

Moreover, throughout the follow-up period, AF episodes were analysed in 5 episodes collected during the 427 days. The duration of these episodes was variable., with 8 patients with episodes longer than 24 hours. Atrial and ventricular activity analysis throughout the episodes provided valuable insight into the arrhythmia evolution.

3. Methods

We have performed 2 types of analysis, one evaluating the information from the days prior to the onset of an AF episode, assessing its different predictability depending on the duration, and the other analysing the activity during 5 episodes, evaluating the evolution of electrical activity throughout the episodes, with the aim of analysing whether there are differences that can predict long-lasting episodes.

3.1. Predicting atrial fibrillation episodes

From atrial activity and daily activity, we analysed activity 5 days prior to each episode:

- Shannon entropy measures uncertainty in atrial and ventricular activity datasets:

$$H(x) = -\sum_{i=1}^{n} p(x_i)\log(p(x_i)) \tag{1}$$

where $p(x_i)$ is the probability of each outcome x_i, representing the individual values of atrial or ventricular activity observed in the dataset. The sum is taken over n possible outcomes.

- The variability which quantifies the dispersion of ventricular and atrial activity over the 5 days prior to the episode, (σ):

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \tag{2}$$

where: x_i refers to each individual observation of atrial or ventricular activity; N is the total number of observations in the dataset and $\bar{x}$ is the mean (average) of the observed values.

- Granger Causality (GC) to assess whether there is a different causal relationship between daily activity and atrial activity in patients with longer duration of AF episodes. Let y_t be the time series of interest, and x_t be the predictor time series. The basic form used in a vector autoregression model is:

$$Y_t = \alpha + \sum_{i=1}^{p}\beta_i y_{t-i} + \sum_{j=1}^{q}\gamma_j x_{t-j} + \epsilon_t \tag{3}$$

Where: α is a constant term; β_i are coefficients for past values of (Y); γ_j are coefficients for past values of (X); ϵ_t is the error term and p and q are the lag orders for the models.

3.2. Atrial Fibrillation Episodes Analysis

Each patient has five recorded episodes of atrial fibrillation (AF), which exhibit variability in duration. In 8 patients, the duration of these episodes increases, reaching up to 24 hours (classified as long episodes), while in others, the episodes remain relatively brief (classified as short episodes). This study aims to evaluate whether there is a correlation between the maximum and mean atrial and ventricular velocities and the duration of both long and short AF episodes. To achieve this, the following analyses will be conducted:

- Assess the correlation between the maximum values of atrial and ventricular activations and the duration of AF episodes.
- Compare the variations and average of atrial and ventricular activities in long and short episodes.

4. Results

4.1. Predicting atrial fibrillation episodes

Higher atrial activity entropy prior to atrial fibrillation (AF) episodes is associated with longer duration events compared to shorter episodes, demonstrating statistically significant differences, p=0.03 (Figure 1). Specifically, the entropy values were notably higher in the longer duration group (3.319±0.002) compared to the shorter duration group (3.320±0.001).

Moreover, increased daily time activity entropy prior to AF episodes is linked to longer duration events (3.16±0.11) when compared to shorter episodes (3.06±0.06), with a statistical significance of p=0.04.

Daily activity showed a stronger causal relationship with diurnal atrial activity from five day before to the onset of shorter AF episodes, with a statistically significant difference observed between the two groups (p=0.046). In particular, the group with shorter duration episodes showed

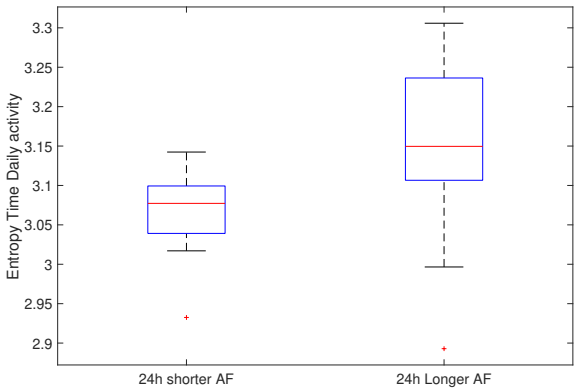

Figure 1. AA entropy in short & long AF episodes.

an average diurnal atrial activity of (84.00±3.24), in contrast to (102.33±1.99) observed in the group with longer duration episodes. (Figure 2)

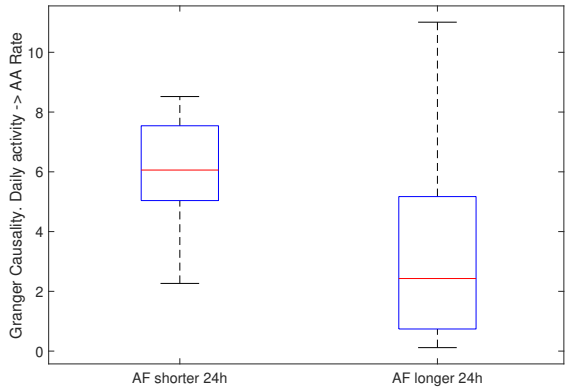

Figure 2. GC Daily Activity $->$ Diurnal AA

4.2. Atrial Fibrillation Episodes Analysis

Variations and mean atrial and ventricular activity (VA) were compared across five episodes of AF that lasted longer and shorter than 24 hours (Table 2).

Table 2. AA & VA during AF episodes

Parameters	Lower 24 h	longer 24 h	Sig(p)
meanAA(bpm)	317.76±150.02	333.79±166.87	0.007
stdAA(bpm)	41.28±23.36	81.41±32.79	0.013
meanVA(bpm)	70.83±15.70	113.69±39.19	0.085
stdVA(bpm)	9.24±7.52	17.40±18.02	0.024

The analysis reveals that the variation atrial activity average during long episodes was greater than that seen in short episodes (Figure 3).

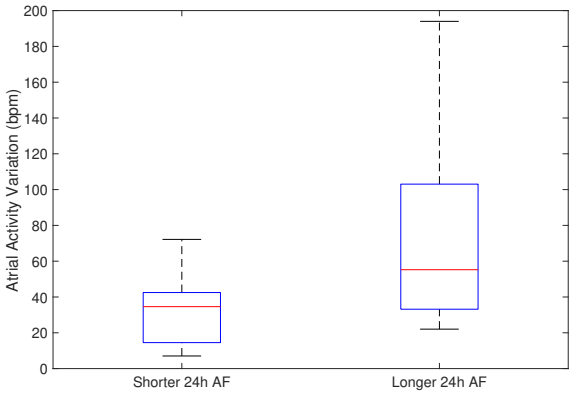

Figure 3. AA variation in short & long AF episodes

Furthermore, it is possible to observe that in long AF episodes lasting over 24 hours, the variation in mean atrial activity is greater than in shorter episodes. This is illustrated in Figure 4, with mean values of 317.76±150.02 for longer episodes and 333.79±166.87 for shorter episodes in both atrial and ventricular activity, respectively (p = 0.007).

In long lasting episodes, the variation in atrial activity average longer 24-hour episodes than in shorter episodes. (Figure 4), with values of 317.76±150.02 and 333.79±166.87 for both atrial and ventricular activity in each group, respectively (p=0.007).

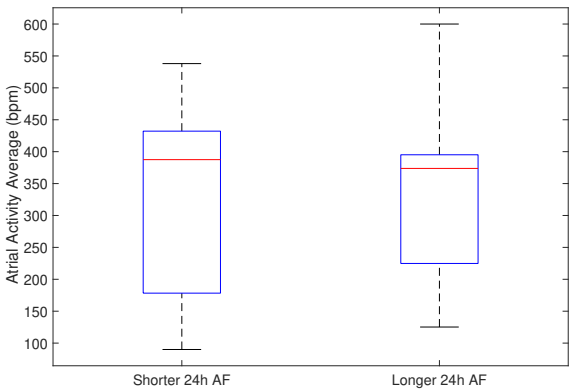

Figure 4. AA avevage in short & long AF episodes

Moreover, the maximum mean ventricular activity in episodes lasting longer than 24 hours was significantly higher, with values of 9.24±7.52 compared to

17.40±18.02 in the shorter episodes, demonstrating a statistical difference (p = 0.024 (Table 2). Nevertheless, statistically significant differences between the two groups were not found in the average ventricular activity although the same trend was followed.

5. Conclusions

The findings from this study highlight the complex relationship between atrial activity entropy, daily activity and the duration of atrial fibrillation (AF) episodes. Specifically, higher atrial activity entropy prior to AF episodes is significantly associated with longer duration even,.This result aligns with previous research showing that increased complexity in cardiac rhythm can indicate a higher likelihood of prolonged arrhythmic events [7].

Moreover, the study reveals that increased daily activity entropy prior to AF episodes is linked to prolonged events, with a statistically significant difference (p = 0.04) between longer and shorter episodes. This is consistent with previous findings that noted that physical activity levels and variability are critical factors in managing AF [8,9].

The observed stronger causal relationship between daily activity and diurnal atrial activity for shorter AF episodes further supports this notion, emphasizing that daily lifestyle factors play a vital role in the dynamics of AF [10]. Statistical analysis of mean atrial and ventricular activities during AF episodes reveals significant differences between long and short episodes, suggesting that monitoring these parameters could assist in predicting and managing longer AF episodes. The increase in mean values for atrial activity in longer episodes compared reinforces the idea that the duration of episodes correlates with elevated atrial activity. This finding may aid in clinical assessments as longer AF episodes are often associated with increased risks of adverse outcomes, including thromboembolic events and heart failure [1].

Our findings suggest that both entropy measures and daily activity levels could serve as valuable indicators for predicting the duration of AF episodes, potentially guiding therapeutic strategies and improving patient outcomes. Future research should continue to explore these relationships and assess how lifestyle might influence AF management.

Acknowledgements

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