Ultra-Short-Term Heart Rate Variability of Home-Monitored Heart Failure Patients: a Case Study

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***Abstract*—This study presents an analysis of ultra-short-term heart rate variability (HRV) from electrocardiographic recordings on two patients with advanced heart failure, waiting for a heart transplant. Classical time- and frequency-domain HRV parameters were assessed, alongside with novel information-theoretic measures computed using non-linear estimators. Our findings demonstrate how all the HRV indices overall discriminate the physio-pathological state before heart failure flare-ups, paving the way for further investigations on the early diagnosis of worsening events in these patients.**

***Index Terms*—heart rate variability, home monitoring, ultra-short-term, heart failure**

I. INTRODUCTION

Daily remote patient monitoring is recognized as the next frontier in clinical support and healthcare management. In this way, healthcare providers can improve patient health outcomes while alleviating the burden on hospitals and medical staff. The growing popularity of wearable devices has further increased the availability of ultra-short-term (UST) recordings ($<$ 5 min), since these technologies enable convenient and continuous monitoring of physiological signals in everyday settings [1]. Heart Rate Variability (HRV) is widely recognized as an important tool for evaluating overall cardiac health and autonomic tone [2], reflecting the cardiovascular system's ability to react to environmental and psychological factors. Indeed, HRV is considered a hallmark of healthy physiological regulation, which often diminishes due to diseases or age-related changes, and it has been proven an useful tool to be employed in heart failure diagnosis and management [3]. The widely-used standard to assess HRV involves the analysis of 300-beat long time series of consecutive heartbeats from electrocardiographic (ECG) signals, but several recent works [1], [4] have demonstrated that even shorter recordings can be deemed reliable to assess autonomic tone and detect physiological changes.

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In this work, we present the results of HRV analysis from ECG home monitoring of two patients with a history of heart failure. HRV parameters are computed from UST beat-to-beat interval time series in time-, frequency, and information-theoretic domains.

II. MATERIAL AND METHODS

A. Subjects and signal acquisition

Two patients with advanced Heart Failure with reduced Ejection Fraction (HFrEF), waiting for heart transplantation, were home-monitored over a four-month period. Patient1 (Male, 73 years old) experienced a flare-up of heart failure during this time, leading to hospitalization, while Patient2 (Male, 68 years old) maintained a stable physiological status throughout. The signals analyzed consisted of at least 1 minute electrocardiogram recordings (Checkme Pro, Viatom Technology, China; sampling rate of 500 Hz) acquired daily by the subjects themselves. For Patient1, the ECG tracks were divided into two groups, i.e. *Before Hospitalization* (BH) and *After Hospitalzation* (AH), which refers to the recovering period at home after hospital discharge. For Patient2, all signals were categorized as *No Hospitalization* (NH), since no notable events occurred during the study.

B. HRV analysis

HRV parameters were assessed using the last 60 beats of each ECG recording. R peak detection was performed using the Pan-Tompkins algorithm, followed by visual inspection to ensure good quality of the signal. Tracks that exhibited excessive noise or contained fewer than 60 beats were excluded from further analysis. RR interval time-series, defined as the time differences between consecutive R peaks, were then computed. Time-domain HRV parameters, including the mean (MeanRR) and the standard deviation (STD) of RR intervals, were calculated to statistically describe cardiac activity timing. Frequency-domain analysis was conducted to assess HRV oscillatory components within Low Frequency (LF, [0.04-0.15] Hz) and High Frequency (HF, [0.15-0.4 Hz]) power bands after

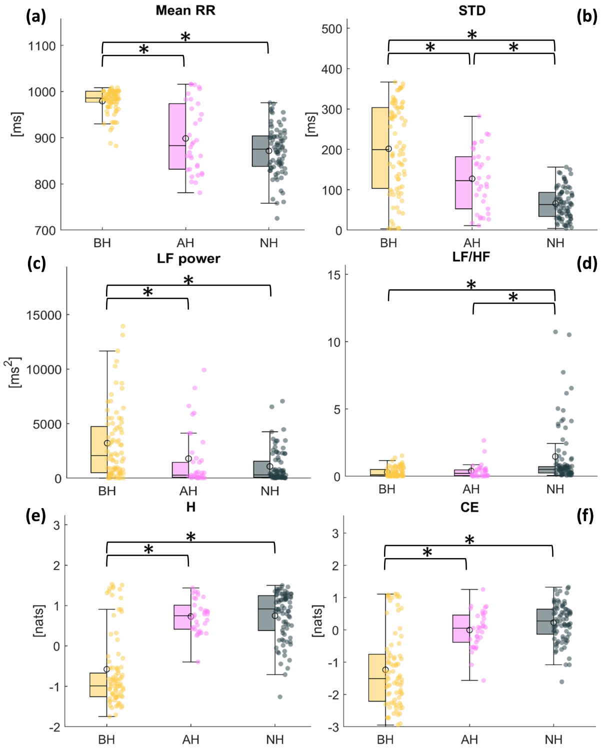

Fig. 1. Distributions and individual values of the indexes computed for the three conditions (BH in yellow, AH in pink, NH in gray). Mean value is reported as a circle. Time-domain HRV parameters: (a) Mean RR, (b) STD; frequency-domain parameters: (c) LF power, (d) LF-to-HF ratio. Information-domain parameters: (e) Entropy and (f) Conditional Entropy. Statistical analysis: Wilcoxon rank test among groups with Bonferroni correction (*, $p < 0.05/3$).

obtaining the power spectral density (PSD) of the RR time series by using the non parametric Blackman-Tukey approach (Hamming window, bandwidth of 0.04 Hz). These two terms have been also employed to compute the LF/HF ratio, a useful index to determine sympathovagal balance [2]. Additionally, information domain analysis was performed to gain insights about cardiac activity patterns. Specifically, entropy (H) and conditional entropy (CE) have been calculated to statically and dynamically evaluate RR intervals variability in terms of uncertainty and complexity, respectively [5], using a k-nearest neighbor approach [6] with m=2 past lags and k=10 neighbors. The two-sided non-parametric unpaired Wilcoxon rank test was employed to assess pairwise statistically significant differences ($p < 0.05$) between the distributions of each measure among the three groups, applying the Bonferroni correction for multiple comparison ($n = 3$).

III. Results and Discussion

Overall, the following ECG tracks were analyzed: 81 BH recordings and AH 34 recordings for Patient1, 79 NH recordings for Patient2. Figure 1 illustrates the differences in distributions of the estimated HRV parameters across these three conditions. Both Mean RR (panel a) and STD (panel b) show higher values in BH and lower values in NH conditions, reporting significant differences for all comparisons except for AH vs NH with regard to Mean RR. The frequency-domain analysis evidences significantly higher LF power values during BH than in the other two conditions (panel c), while LF/HF ratio appears significantly higher during NH (panel d). Our findings agree with previous results suggesting that HRV tends to decrease in patients in more advanced stages of HFrEF. Specifically, for subjects at major risk of heart failure events, an higher sympathetic activation was found [7]; the latter finding is here supported also by the lower complexity of HRV (lower CE) measured in the BH recordings. This observation has to be interpreted considering the complex interplay between the reported higher sympathetic activation in these patients, counterbalanced by a perhaps sub-optimal ongoing beta-blocker therapy. Both entropy (panel e) and conditional entropy (panel f) terms show significantly lower values in BH condition, indicating a stronger inability of cardiac dynamics to react to physiological changes, as reported in previous research on pathological subjects [8]. Finally, the discordant trends of STD (panel b) and H (panel e) terms also support the non linear behaviour of cardiac dynamics in heart failure patients [8], [9].

IV. Conclusions

This work has the purpose to demonstrate the feasibility of using ECG home-monitoring to perform a continuous assessment of cardiovascular variability through UST recordings in patients with advanced HFrEF. Despite still being a case study, our findings reveal a consistent discrimination between before and after heart failure flare-up, while a general similarity between AH and NH is noticed. On one hand, these results likely indicate a shift towards a more stable physiological state post-hospitalization. Moreover, HRV analysis could be useful in HFrEF population to identify patients with stronger sympathetic activity, in need of a more effective beta-blocking therapy. While this study analyzes multiple recordings per patient, a more comprehensive investigation involving a larger cohort of patients would be necessary to strengthen the robustness of the obtained findings.

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