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Effect of Atrioventricular Conduction on Heart Rate Variability

Talha J. Ahmad*, Hussnain Ali, *Student Member, IEEE,* S.M. Imran Majeed and Shoab A. Khan

Abstract— **This paper discusses the effect of atrioventricular conduction time (AVCT) on the short-term Heart Rate Variability (HRV) by computing HRV parameters using intervals between the onsets of successive P waves (PP time series) for three groups: normal, arrhythmia and sudden cardiac death (SCD) patients. A very precise wavelet transform based ECG delineator was developed to detect PP, PR and RR time series. Mean PR variation in arrhythmia and SCD group was found to be significantly high as compared to the normal group. It was observed that when PR variations in arrhythmia and SCD cases crossed a certain threshold, RR variability no longer provided a very accurate estimate of HRV. In such cases, PP variability was able to provide a better assessment of HRV.**

I. Introduction

AUTONOMIC nervous system (ANS) is part of the peripheral nervous system that acts as a control system regulating various important organs and physiological functions of the body [1]. As heart is one of these organs, beat to beat variations in heart rate (HR) are also regulated by the ANS activity. So the analysis of variations in circadian rhythm can provide an understanding of ANS mechanism and can help in identifying abnormalities within the ANS caused by many pathological conditions and physiological changes [1]. Heart Rate Variability (HRV) analysis is a simple, effective and an efficient diagnostic technique which can provide a theoretical framework for ANS assessment by identifying the sympathetic and parasympathetic activities and can be used as a method to assess a person's cardiac details [1, 2]. Several studies have demonstrated that HRV is the most promising marker for the prediction of morbidity and mortality risk for some cardiovascular diseases including sudden cardiac death and diabetic neuropathy [1, 3]. It has also proved to be a strong predictor of mortality in patients after myocardial infarction [4, 5]. Beside cardiac diseases, HRV may vary due to age, neuropathy, respiration, maximum inhalation and cardiac load [1]. Higher HRV has been linked to psychological resilience and normal cardiac autonomic modulation and conversely lower HRV is linked to abnormal cardiac autonomic modulation caused by different cardiovascular diseases and disorders [6, 7].

HRV analysis can be done on both short-term (2-10 minutes) and long-term (24-48 hours) ECG recordings. Several HRV analysis methods have been proposed in the literature which can be divided into time domain, frequency domain and non linear dynamics methods.

First step in the HRV analysis is detection of each heart beat. In order to assess autonomic regulatory effects on HR, it makes most physiologic sense to detect the occurrence of sinus nodal events or the beginning of atrial depolarization. So the normal-to-normal (NN) series should be computed by calculating the intervals between the onsets of successive P waves (PP) in an ECG signal. In practice, this is technically difficult and HRV measurement is usually based on the sequence of RR intervals (intervals between successive R peaks) instead. This practice neglects the potential presence of fluctuations in PR intervals caused by variations in atrioventricular conduction time (AVCT), which is linked to the sympathetic/parasympathetic activities of the ANS [8]. PR intervals vary significantly in various cardiac abnormalities, especially in Wenckebach phenomenon [9] and in patients with atrioventricular (AV) block [10]. Even in normal subjects the standard deviation of PR intervals ranges from 0.5 to 5 ms [9]. This variation in PR intervals can result in a significant change in HRV. HRV analysis performed using PP intervals can provide a better assessment of cardiac activity in many pathologies.

In this work we have developed a very precise wavelet based ECG delineator to detect PP, PR and RR intervals. Next, we have performed short-term HRV analysis using RR as well as PP intervals. The analysis is performed on normal, arrhythmia and sudden cardiac death patients to study the effect of cyclic variations in AVCT on different HRV parameters. Variations in these parameters computed using RR and PP intervals within the same patient group and in different groups is studied.

II. Methods

A. ECG Data

Since accurate delineation of P wave was critical, Physionet QT database (QTDB) [11] was used in this study. Three groups of patients: Normal, Arrhythmic and Sudden Cardiac Death were studied. Each group contained ten ECG records of different patients from MIT-BIH Normal Sinus Rhythm (NSR), MIT-BIH Arrhythmia and Sudden Cardiac Death (SCD) databases given in QTDB. As short-term HRV analysis was performed in the study, five minutes duration

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Talha J. Ahmad is with Department of Electrical Engineering, King Abdullah University of Science and Technology, KSA (e-mail: talhajamal@live.com)

Hussnain Ali is with Department of Electrical Engineering, University of Texas at Dallas, Richardson, TX 75080 USA (e-mail: hussnain@ieee.org).

S. M. Imran Majeed is with Department of Cardiac Electrophysiology, Armed Forces Institute of Cardiology, Rawalpindi, Pakistan

Shoab A. Khan is with Department of Electrical Engineering, College of Electrical and Mechanical Engineering, National University of Sciences and Technology, Rawalpindi, Pakistan.

of each ECG record was used. ECG records in QTDB are sampled at 250 samples per second. Signals with significant P wave for at least five minutes of signal duration were used in the study.

B. ECG Delineator

In this work, we have developed a dyadic wavelet transform (DWT) based ECG delineator [12] to detect QRS complex and onset of P waves with high accuracy. DWT was implemented with Mallat's algorithm [13] and a quadratic spline was used as the basic wavelet. First four scales of DWT were used for delineation. Details of the algorithm can be found in [13]. Delineator was evaluated on QTDB. For QRS detection, delineator obtained a Se of 99.75% and a P+ of 99.46%. For P wave onset delineator obtained a Se of 97.8% and a P+ of 90.7% with a mean error of 4 ms.

C. RR and PP preprocessing

For calculating RR and PP tachogram, R peak and P onset point from the same beat was taken. If the precise location of P wave onset in a beat was not determined or the detection error was greater than 4 ms, that individual beat was discarded altogether.

Next step in preprocessing of RR and PP series is elimination of ectopic beats. As ectopies usually result in sharp transients in tachogram, raw tachograms are not used for HRV analysis. Ectopic beats were removed using timing and morphology information of each beat using technique described in [14]. After the removal of ectopies, both tachograms were re-sampled at 4 Hz with linear interpolation. A check was made to ensure that RR and PP series is of the same length and the corresponding R and P onset point are from the same beat. All isolated R and P onset points were removed from the series.

D. HRV Analysis

Short-term Heart Rate Variability analysis was performed on the processed RR and PP series. As the time and frequency domain measures are not adequate to characterize the complexity of the HRV and provide little information on the nonlinear dynamics of HRV, a number of nonlinear analysis methods were also employed for HRV analysis. Nonlinear techniques employed in the study include approximate entropy, sample entropy, detrended fluctuation analysis, information based similarity index, Multiscale entropy analysis, modified Karhunen-Loeve' transform, T wave-alternans and heart rate turbulence. The detail of HRV analysis methods can be found in [1] and [15].

III. RESULTS

Fig. 1 shows the mean PR intervals and variation in PR intervals for three different NSR, arrhythmia and SCD patients' groups. Mean PR interval variation in arrhythmia and SCD group was found to be significantly higher as

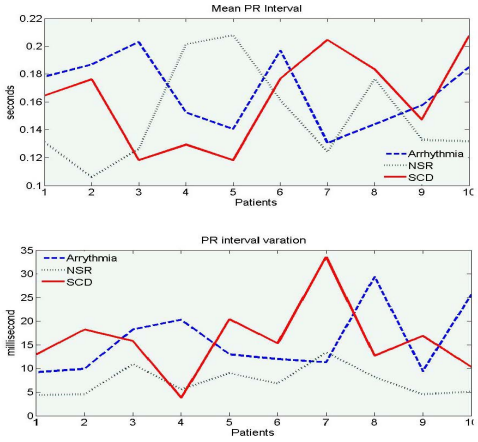

Fig. 1. a) Mean PR interval, b) PR interval variation

compared to the normal group. The mean PR variation was found to be 7.2 ms in NSR as opposed to 15.83 ms in arrhythmia and 15.05 ms in SCD group. In most of the SCD records, the variation was more than 12 ms and this value reached 25.6 ms for patients with AV block, resulting in a significant change in various HRV parameters. Table I shows HRV time domain parameters calculated for all patient groups using RR and PP Intervals.

In time domain parameters, significant difference was seen in SDNN, STD HR, RMSSD, pNN50 and HRV triangular index values when calculated with PP intervals. It can be noted from Table I that this difference becomes more significant in case of arrhythmia and SCD patients as compared to NSR group. This is due to the higher variations of AVCT in different cardiac arrhythmias which may be associated to the ANS activity.

As far as frequency domain parameters are concerned, peak frequencies of VLF, LF and HF bands are nearly same for both RR and PP intervals of NSR and arrhythmia group. Only difference found is in the SCD group, where HF peak frequencies get closer to LF band. Absolute powers in all patient groups increased when calculated using PP intervals. It can be noticed from Table II that in case of SCD group, higher value of HF band power and lower LF/HF ratio calculated through PP intervals gives us a better estimate of parasympathetic/sympathetic activity and sympathovagal balance.

Poincare plot provides the graphically representation of correlation between successive NN intervals and have proved to be a significant classification marker to distinguish between normal and arrhythmia patients. Although Poincare plots for NSR group using PP and RR intervals are nearly similar with a slight difference in short and long term variability, but there were a few arrhythmia and SCD patients (Fig. 2) with a significant change in PR interval, for which poincare plot geometry was more pronounced with PP intervals rather than RR intervals. Results of some of the nonlinear methods are represented using box-whisker plots in Fig. 3. A significant change was observed in approximate entropy, sample entropy and recurrence plot in most of the

TABLE I
HRV TIME-DOMAIN MEASURES

HRV Parameter	NSR		Arrhythmia		SCD	
	RR	PP	RR	PP	RR	PP
Mean RR (ms)	935.5±108.8	935.5±108.8	894.79±207.8	894.75±207.8	917.72±316.5	918.71±317.11
SDNN (ms)	58±32.02	60.8±32.15	42.19±29.64	45.33±27.5	38.6±26.04	42.27±27.5
Mean HR (/min)	65.17±7.04	65.19±7.04	70.82±17.83	70.84±17.84	71.51±20.15	71.52±20.27
STDHR (/min)	4.03±1.87	4.23±1.89	2.99±1.19	3.35±1.08	2.79±1.64	3.05±1.78
RMSSD (ms)	52.76±35.43	59.83±33.36	41.93±25	47.9±23.6	44.14±37.8	52.72±38.43
NN50 (count)	72±51	94±51	50±47	63±40	37±41	53±47
pNN50 (%)	27.7±25.68	34.11±23.5	20.55±20.83	26.48±20	20.61±26.09	26.08±26.3
HRV Index	12.04±5.05	12.10±3.97	9.23±4.94	10±3.876	7.925±5.15	8.4±5
TINN (ms)	185±91	198±93	119±95	131±79	226±120	121±101

TABLE II
HRV FREQUENCY-DOMAIN MEASURES

HRV Parameter	NSR		Arrhythmia		SCD	
	RR	PP	RR	PP	RR	PP
LF (n.u.)	55.42±17.22	50.76±15.3	38.66±22.5	35.79±23.8	44.12±16.3	42.9±11.18
HF (n.u.)	44.56±17.22	49.23±15.29	61.33±22.5	64.2±23.8	53.57±14.19	57.03±11.18
LF/HF	2.11±3.01	1.47±1.75	0.949±1	0.922±1.13	1.02±0.68	0.818±0.364

arrhythmia and SCD patients where PR variations were significant. Even though a direct correlation between results obtained by using RR or PP intervals and PR variations could not be observed but a significant difference in all the parameters in various arrhythmic and SCD signals was evident, depending upon the degree of autonomic modulation of AV conduction.

IV. DISCUSSION

HRV analysis was performed on NSR, arrhythmia and SCD patient groups to study the effect of AVCT on different HRV parameters. It was observed that the degree to which the ANS influences AVCT varies from individual to individual and disease to disease. A very small difference in HRV was observed in case of normal subjects but this difference became very prominent in case of arrhythmic and SCD patients due to variations in AVCT. Although a precise value of PR variation threshold could not be calculated but it was observed that in most of the studied arrhythmia and SCD cases, PR variation more than 12 ms resulted in a significant change in HRV parameters. It is in these cases, HRV computed using PP intervals better characterized the underlying pathology.

A considerable change in parasympathetic variables was observed in patients with AV block. Values of SDNN, RMSSD, pNN50, HRV triangular index, TINN, SD1, SD2 and approximate entropy increased while decrease in sample entropy and scaling exponent for DFA was observed when computed using PP intervals. Significant changes in the peak frequencies and absolute power were observed. Decrease in relative power of VLF and LF band and an increase in relative power of HF band was also observed which indicates a change in parasympathetic and sympathetic activity, not evident through RR intervals. Moreover, an increase in sympathovagal balance was also observed.

Although no linear correlation was found between different HRV parameters calculated either from PP or RR intervals in arrhythmia group due to the natural intrinsic variability in ANS activation of the AV node, but a nonlinear correlation may exist between PR variations and different HRV analysis techniques, especially in case of patients with AV block. As complete AV block with severe bradycardia may increase the risk of ventricular tachycardia or ventricular fibrillation [10], therefore, PP intervals could be a better diagnostic indicator and/or predictor of mortality.

As significant PR variations were present in SCD group and a considerable change in short-term HRV was observed, there may be a significant impact of these variations on long-term (24 hours) HRV. However, problem in most of the holter recordings is accurate detection of P wave onset in low SNR conditions. Therefore, unavailability of sufficient amount of PP series for a thorough analysis of the effect of AVCT on long-term HRV during various physiological states is still a challenging task. A comprehensive study with enlarged dataset and longer recordings is required to investigate the statistical significance of PP intervals as a better marker for HRV analysis, especially for arrhythmia related to AV block.

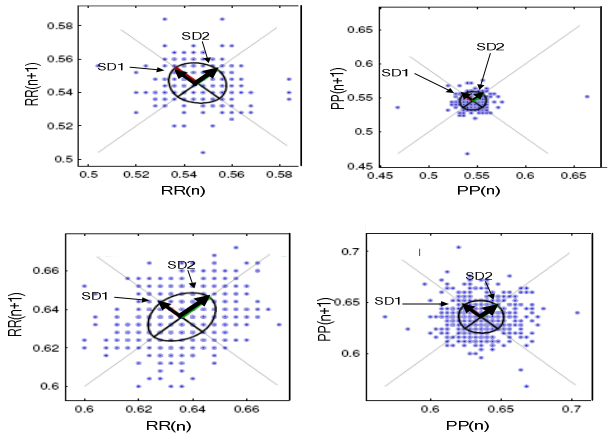

Fig. 2. Poincare plot for Arrhythmia and SCD ECG signal

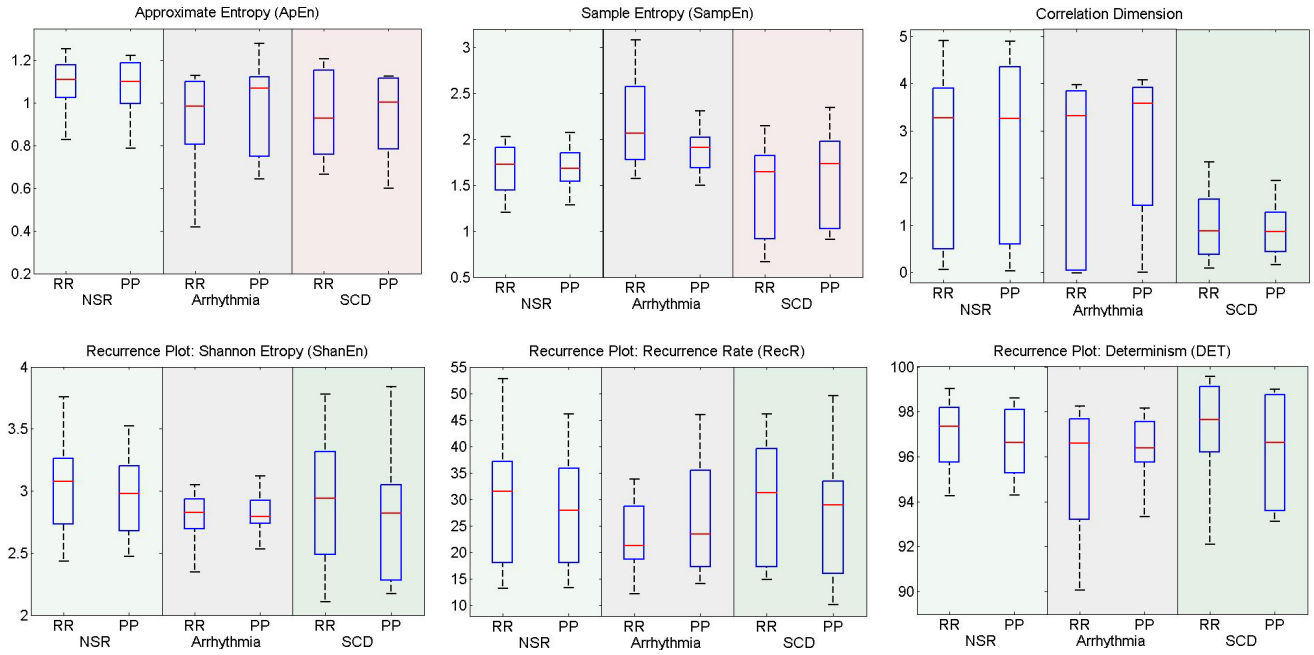

Fig. 3. HRV nonlinear dynamics parameters

V. Conclusion

The study aimed to provide information on the use of PP as compared to RR time intervals for the heart rate variability assessment. The study is supported by experimental results which suggest the potential development of HRV as a marker of not only the autonomic nervous system but also the relationship between the ANS and the functioning of the myocardium as indicated by more marked differences between RR and PP intervals in cases of arrhythmia and sudden cardiac death, concluding that PP time intervals can be a better diagnostic marker for life-threatening arrhythmias. Researchers in this area are encouraged to further investigate the effects of AVCT on larger population as well as on longer recordings which would give us further insight of the complex dynamics of ANS and myocardium.

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