Cardiac Autonomous Function Assessment in Congestive Heart Failure using HRV Analysis

Ulka Shirole, Manjusha Joshi, Pritish Bagul

Abstract-- According to world health organization (WHO) maximum death is caused by cardiac health issues. Heart Rate Variability (HRV) is considered a good pointer of autonomic regulator related to cardiovascular health. HRV has been studied in a variety of situations in order to determine the variables that influence it. Autonomous Nervous System (ANS) dynamics is estimated through standard and nonlinear analysis of HRV which is derived from the electrocardiogram (ECG). HRV provides parameters of autonomous activity which are related to cardiac health. In this paper, a new health index called "Orthostatic Stress Index" (OSI) is proposed to rank patients from lower risk to higher risk. This index is obtained using frequency domain analysis parameters LF, HF, and sympathovagal balance. In this study data is collected from subjects with age range of 30-65 years. Subjects suffering from cardiovascular diseases, diabetes, and hyper tension are compared with control subjects. Results clearly indicate the risk factors using OSI are comparable with the clinical symptoms of the patients.

Keywords-*Heart Rate Variability, Autonomous Nervous System, Cardiac Health, Orthostatic stress index.*

I. Introduction

According to world health organization (WHO) maximum death is caused by cardiac health issues. According to WHO [1], cardiac diseases contribute to 31% of overall diseases. Cardiac diseases include heart and blood vessel abnormalities. There are different type of cardiac diseases like coronary artery diseases, peripheral artery diseases, cerebrovascular, renal artery stenosis, etc. ECG signal is a non-invasive method to understand the health of the heart and its beats. Heart rate variability is the degree of fluctuation in the length of the intervals between heart beats. It mirrors the regularity of heart beats: greater the regularity, lower the HRV (and vice versa). Regularity of heartbeats is derived from a quantity of numbers; equal to the times elapsed between successive heartbeats. They are named R - R intervals and are measured in milliseconds (ms). Fig. 1 shows the HRV calculation using the ECG signal. Heart Rate Variability (HRV) is considered a good measure of autonomic control related to cardiovascular health [5,6]. HRV is influenced by many factors such as age, gender, heart disease, neurological disease and exercise. HRV is direct indicator of sympathetic and parasympathetic nervous system. When sympathetic activity predominates HRV is known to decrease whereas it increases when parasympathetic activity predominates. HRV thus reflects autonomic control of the cardiovascular system [5].

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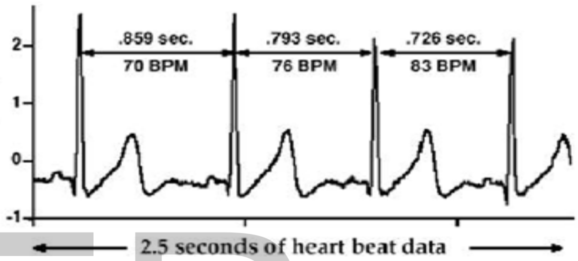

Figure 1. HRV signal, peak-to-peak signal illustration to calculate HRV [8]

Number of populations suffering from cardiac diseases is rapidly increasing. Sympathetic and parasympathetic nervous system that voluntarily respond to external stimuli. Sinus node, which generates the electrical impulses, is required for heart pumping that affects sympathetic and parasympathetic nervous system. Balance between sympathetic and parasympathetic nervous system, called sympathovagal balance, is important for normal functioning of a subject. When a subject is placed to mental stress or any physical activity, sympathetic tone is augmented at the same time parasympathetic tone is reduced to maintain sympathovagal balance. Vagal tone is high during resting conditions. Increased demand from the body requires that increase in the pumping capacity of heart and hence raises sympathetic tone. The sympathovagal balance is good in healthy subjects, however sympatovagal imbalance is evident in subjects suffering from cardiac disease, hypertension, diabetes, or subjects undergone heart surgery.

HRV analysis can be done by using different methods. According to the European Society of Cardiology and the North American Society of Pacing and Electro- physiology [5], the Time domain, Frequency domain and Poincare plot are the most widely-used methods [5]. Though there are available, no valid reference data for measuring parameters in the frequency domain or the poincaré plot. There is need to understand the values of high and low frequency (HF and LF) and the transversal (SD1) and longitudinal diameters (SD2) of the poincaré plot to assess the autonomic control of the cardiovascular system in the light of earlier studies. In case of the chronic heart failure and acute myocardial infarction time domain parameters such as SDNN, pNN50, and rMSSD are

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used for categorizing high and low risk patients. The association of decreased HRV and mortality rate has generally been validated for the peri-infarction period [7]. Useful reference data are available in the time domain for the evaluation of HRV at rest, they are related to the assessment of cardiovascular risk; it is not clear whether they can be generalized to healthy young people, or to what extent they are meaningful for judging the significance of other factors, such as exercise, meditation etc. However, there are no valid reference data available for assessing parameters in the frequency domain or the poincaré plot. Therefore, there is need of some direct index to measure the cardiac health issues of subjects based on either time domain or frequency domain parameters.

In this paper, a new health index called "Orthostatic Stress Index" (OSI) is proposed to rank patients from lower risk to higher risk. This index is obtained using frequency domain analysis parameters LF, HF, and sympathovagal balance. Calculation of the index is straight forward and thereby allowing practitioner for judging the health of subject. Our experimental results support indicative rank for assessing health of the patients.

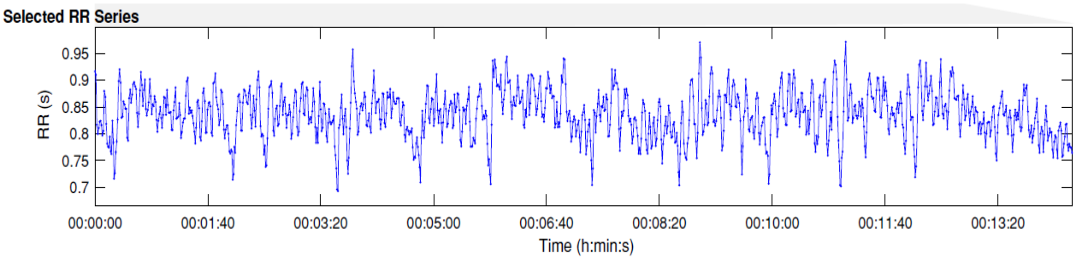

Figure 2. A typical R-R series for a normal subject

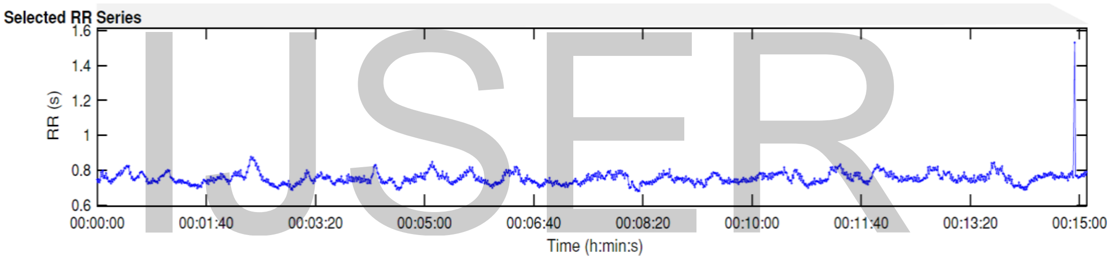

Figure 3. A typical R-R series for a subject with blockages

Fig. 2 and Fig. 3 show a typical R-R series for a normal subject and diseased subject, where time is on X-axis and R-R interval values are on Y-axis. It can be observe that variation in the RR time interval is more in healthy subject whereas it is low in diseased subject. A subject shown in Fig. 3 had blockages and bypass surgery was suggested by the physician. This leads to decrease in HRV due to decrease in vagal activity. Thus, it is interesting to observe the R-R interval distribution histogram and AR spectrum of healthy subject and diseased subject.

IV. Data Collection

In this study, clinical data is collected for total 26 subjects, where 11 patients suffering from congestive heart failure and 15 healthy subjects. Subjects involved in the study are having age in the range 30-60 years. ECG data was collected for these patients, who were suffering from congestive heart failure, from B and J super specialty hospital Kamothe, Navi Mumbai. Patients' ECG data is collected using a 12 electrode ECG acquisition machine based on the PC ECG software. PCECG software acquires data of all 12 channels and stores in the XML file. ECG data is recorded for 15 minutes in sitting position and 15 minutes in supine position. Sampling rate of 500Hz is used, the system has generated ECG digital Data in XML format for 12 channels separately. Collected data is used to study the response of heart. Out of 12 channels, we selected signal from second channel for analysis.

II. Analysis Method

R –programming script is written to extract channel-2 data from XML file, which contains combined 12 channel data and other information. Text and special characters are removed from extracted channel-2 data and only samples are written to a text file. The result of R- programming script, a text file input is to the Kubios software for further analysis. Kubios HRV (available at: http://kubios.uku.fi), developed using Matlab by the Biosignal Analysis and Medical Imaging Group at the University of Kuopio(Finland). Kubios, HRV analysis software, provides time domain and frequency domain information. Kubios analysis information is used to cardiac health assessment. It provides time domain parameters such as mean RR interval, SDNN, mean RR, NN50, and pNN50, and frequency domain parameters such as power in the VLF (0−0.04 Hz), LF (0.04−0.15 Hz), HF (0.15−0.4 Hz) and

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LF/HF ratio. The original ECG signal were processed through a low-pass filter with a cut off frequency of 15Hz to remove noise. Next the signal was passed through a high-pass filter with a cut-off frequency of 0.3 Hz to remove baseline wander [2].

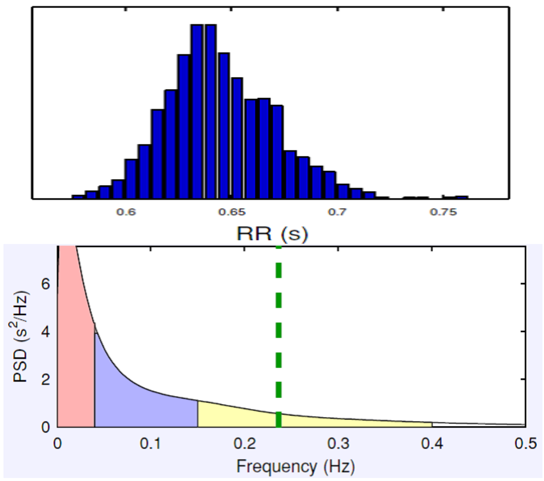

Figure 4. Histogram of RR interval and AR spectrum of RR interval series of a healthy subject, ECG recorded in supine position.

Fig. 4 shows R-R interval distribution histogram and AR spectrum of a healthy subject in supine position. Fig. 5 shows R-R interval distribution histogram and AR spectrum of a subject with cardiac disease in supine position. From Fig. 4 and Fig. 5, it is evident that R-R interval spread is more for the healthy subject compared to the cardiac disease subject. Moreover, AR spectrums of both subjects looks similar, but their power spectral density (PSD) is different. In other words healthy subjects have high PSD and diseased subjects have low PDS.

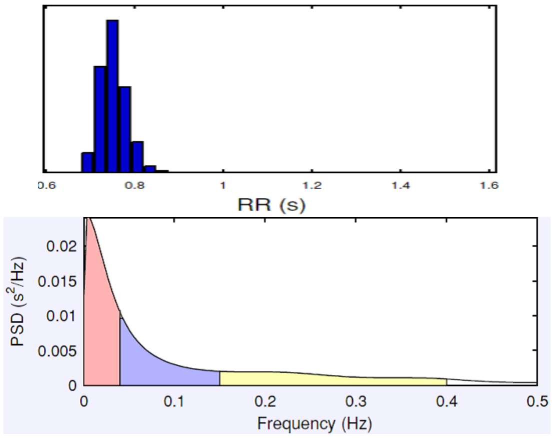

Figure 5. Histogram of RR interval and AR spectrum of RR interval series of subject with cardiac disease (who was suggested Bypass surgery), ECG recorded insupine position.

Human body position considerably stimuluses cardiac autonomic drive. Autonomic balance is clearly different between supine and sitting positions. Parasympathetic nervous function predominates in supine positions, while Sympathetic function predominates in sitting positions. The effect of these positions in healthy subjects and disease subject gives significant information of cardiac health of the subjects. Based on information collected, we define an empirical formula called "Orthostatic Stress Index", which gives a rank to the subjects based on their cardiovascular health. This index is based on the sympathovagal balance of supine and sitting positions.

III. Orthostatic Stress Index Calculation

Orthostatic stress index is calculated from sympathovagal balance (LF/HF) parameter obtained from HRV analysis of ECG signal. It is expressed as

$$\mathrm{OSI} = \frac{\left(\frac{LF}{HF}\right) sitting - \left(\frac{LF}{HF}\right) supine}{\left(\frac{LF}{HF}\right) sitting} \qquad (1)$$

Where, LF/HF is ratio of sympathetic power to parasympathetic power. This ratio is expected to be low in supine position, because parasympathetic power dominates sympathetic power in supine position.

IV. Results and Discussion

Table 1 summaries LF/HF ratio and OSI for 15 the subjects and their clinical symptoms. The subjects are ranked in the table according to OSI value and it is observed that there is a correlation between OSI index and clinical symptoms. As LF is related with sympathetic power and HF with parasympathetic power, HF power is low in supine position (parasympathetic power) and LF is high in sitting position (sympathetic power).

TABLE I. Subjects' information containing, HRV frequency domain parameters and OSI calculation

PID	Gender	Cardiac Disease	Diabetes	Hypertensive	(LF/HF) supine	(LF/HF) siting	OSI
1	M	YES	YES	YES	8.739	2.014	-3.33913
2	M	YES	NO	NO	6.297	1.601	-2.93317
3	M	YES	NO	NO	1.8509	0.47871	-2.86643
4	M	YES	YES	NO	0.299	0.084	-2.55952
5	F	YES	YES	NO	5.5319	2.0686	-1.67422
6	M	YES	YES	NO	2.6439	1.1289	-1.34201
7	F	YES	NO	NO	1.0249	0.55206	-0.8565
8	M	YES	NO	NO	4.303	2.346	-0.83419
9	F	YES	NO	NO	0.58602	0.41572	-0.40965
10	F	YES	YES	NO	0.92879	0.73383	-0.26567
11	F	NO	NO	NO	5.5809	4.4766	-0.24668
12	M	NO	NO	NO	1.253	1.1056	-0.13332
13	F	YES	YES	NO	0.568	0.524	-0.08397
14	F	NO	NO	NO	0.70649	0.67859	-0.04111
15	F	NO	NO	NO	0.70649	0.70649	0
16	F	NO	NO	NO	0.1902	0.1902	0
17	M	NO	NO	NO	3.7997	3.7997	0
18	M	NO	NO	NO	1.3189	1.3189	0
19	M	NO	NO	NO	8.162	8.2367	0.009069
20	F	NO	YES	NO	1.533	1.884	0.186306
21	F	NO	NO	NO	1.9908	2.5121	0.207516
22	M	NO	NO	NO	4.031	5.185	0.222565
23	M	NO	YES	NO	3.647	5.017	0.273072
24	F	NO	NO	NO	3.7997	5.4918	0.308114
25	F	NO	NO	NO	2.0686	3.1875	0.351027
26	M	NO	NO	YES	0.19837	0.32275	0.385376

Therefore LF/HF ratio is expected to be low in supine and high in sitting position in normal subjects. But in case of subjects suffering from cardiac diseases sympathovagal balance is not maintained because of reduced performance of heart. From the calculations it is observed that OSI index is low for the cardiac patient as it is expected.

Result also shows that LF/HF ratio is high for the subject suffering from cardiac and have diabetes.

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