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Assessing Heart Rate Variability and Pulse Rate Variability Patterns in Cardiac Patients: Exploring the Utility of Photoplethysmography and Electrocardiography

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The measure of cardiac variability (HRV) is considered an accurate diagnostic method to identify autonomic dysfunction. The heart rate influences the pulse. Therefore, pulse rate variability (PRV), like HRV, precisely indicates autonomic nervous system tone. The research investigates the correlation between HRV for the ECG signal and PRV in a cardiac patient. 53 electrocardiogram (ECG) and photoplethysmogram (PPG) signals for 8 minutes from the PhysioNet BIDMC PPG and Respiration Dataset were used. Afterward, the PRV from PPG and the R-R interval calculated independently using Acqknowledge software were used to estimate the ECG and get HRV characteristics. According to the results, there was a strong correlation between the R-R interval for PRV (694.49 ± 112.98ms) and HRV (695.60 ± 112.97ms) (r=0.99). For all linear parameters for both domains, frequency and time of HRV and PRV, there was a significant positive correlation: HFnu (r =0.99), HF Power (r =1), LFnu (r = 0.99), LF Power (r = 1), RMSSD (r = 0.99), SDNN (r = 0.99), NN50 (r = 0.99), and pNN50 (r =0.99). The Bland & Altman plot demonstrated a high level of agreement among approaches for all parameters. According to the finding, which showed a high level of agreement because it provides values similar to PRV and HRV for all parameters, the idea of PRV rather than HRV can be used to assess sympathovagal regulation in a broad community-based investigation alongside HRV under various clinical circumstances.

Keywords: Electrocardiogram; Heart rate variability; Heart rate; Photoplethysmography; Pulse rate variability.

Over twenty years ago, a working committee of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology established heart rate variability as the period between two successive heartbeats[1]. HRV has been used to establish a specific cardiac vagal tone index for the parasympathetic nervous system[2,3]. Heart rate variability (HRV) has emerged as a noninvasive marker of autonomic nervous system (ANS) activity, reflecting the dynamic balance between sympathetic and parasympathetic influences on the heart. HRV analysis is fascinating in human performance and health monitoring, where it has been linked to various physiological and psychological states, including stress, fatigue, and recovery[4]. Many factors influence measures of heart rate variability, such as age, obesity, and postural changes, resulting in altered autonomic nervous system tone and stress index measures[5].

Additionally, HRV is a straightforward, affordable, and noninvasive assessment that appeals to many cardiology and psychophysiology researchers. The interbeat interval (IBI), photoplethysmography, and electrocardiogram (ECG) are methods of measuring heart rate variability (HRV)[6]. While ECG recordings have higher accuracy and are more helpful in detecting ORS or R peaks and adjusting for electrode errors, traditional devices use them to estimate heart rate variables[7 8]. The time between heartbeats is estimated utilizing polar heart rate or chest belt records equipment because contemporary technologies use IBI to assess HRV[9]. These models' major problems are inaccurate IBI detection and artifacts brought on by skin motion, as well as the fact that they only use IBI and not accurate ECG signal, R-wave, or QRS detection[10].

Regarding a method of measuring pulse rate variability (PRV), photoplethysmography (PPG) digitizes observations of absorbed light, which changes with periodic circulation in the arteries[11]. In a few earlier studies, an association between HRV and PRV has been shown[12 13]. According to several studies, a smartphone or inexpensive equipment might also be used by anyone to measure PRV rapidly [14 15]. PPG has experienced a revival in recent decades thanks to developments in optoelectronics and digital signal processing, and it is now likely the most widely utilized technique in clinical monitoring. PPG technology has the advantages of being non-intrusive, affordable, and simple to use [6].

An oximeter for pulse (PO) is available by default in medical centers, and the analysis of HRV in the surveillance process without necessitating an electrocardiogram (ECG) has a significant benefit. Other than for MRI (magnetic resonance imaging), it is prohibited to use ECG electrodes or other metal-containing sensors because they can interfere with powerful electromagnetic fields. Compared to an ECG, which typically requires at least three leads and electrodes, the PPG signal can often be detected by just placing a single sensor on a finger or earlobe. These electrocardiogram electrodes frequently need to be put in the chest, necessitating patients to undress and presenting a problem for patients[16].

Therefore, the aim is to investigate the correlation between HRV for the ECG signal and PRV in a cardiac patient.

MATERIAL AND METHOD

Data

The data in this investigation included the physiological signals of 53 patients (21 men and 32 women) aged between 19-96 from the PhysioNet Dataset. The Electrocardiogram (ECG) and Photoplethysmogram (PPG) signals records are about 8 minutes, and the sampling rate is 125 hertz (Hz). Data and patient notations were collected from critically ill patients during their hospitalization at Beth Israel Deaconess Medical Centre (Boston, MA, USA) [17 18].

Analysis method

After obtaining the data containing many signals, such as the ECG with three leads (II, V1, V5), PPG, and respiratory impedance signal, two signals were chosen: lead II, because it gives a higher peak than the other leads for the ECG signal, and the PPG signal to use in the HRV analysis. Then, using the Acqknowledge 5.0 software, which was attached to the BioPac system (MP160, USA), HRV parameters were produced together with estimates of the PRV from the PPG signal, and the R-R interval was calculated independently for the ECG signal. For HRV analysis, the linear mode was used with the time and frequency domains. The standard deviation of (RR, PP) interval (SDNN), root mean square of (RR, PP) interval adjacent (RMSSD), number of (RR, PP) upper 50ms (NN50 COUNT), proportion of NN50 (PNN50%), power spectral of low frequency (LF in ms), high frequency (HF in ms), normalized unite for LFnu, HFnu. The proportion of LF/HF for the time and frequency domains was calculated, respectively.

Statical analyzing

The data was statistically analyzed using SPSS software version 26. For continuous variables, the mean and standard deviation are provided. The variances in measurements were compared using a paired-sample t-test. The Bland-

Altman approach and standard linear regression were used to test the agreement method, and the coefficient of correlation (CC) was calculated using the Spearman rank correlation method. It was decided to use a correlation coefficient to denote a suitable level of relationship [19 20]. *A p-value* was chosen ($p< 0.05$).

RESULTS

According to the results obtained, such as shown in Table 1 and figures, firstly, from the calculation of RR and PP intervals, we find that both signals provide close values for all parameters of HRV.

Every variable has a p-value greater than 0.05. for all parameters delivered from the ECG and PPG signals. All parameters either in the frequency domain or in the time domain for both signals showed a strong correlation (LFnu, HFnu, and proportion of LF/HF), (RR intervals, SDNN, NN50, RMSSD, and pNN50), (r e" 0.99, $p>0.05$). Every feature for each patient generated from the ECG and PPG exhibits good agreement

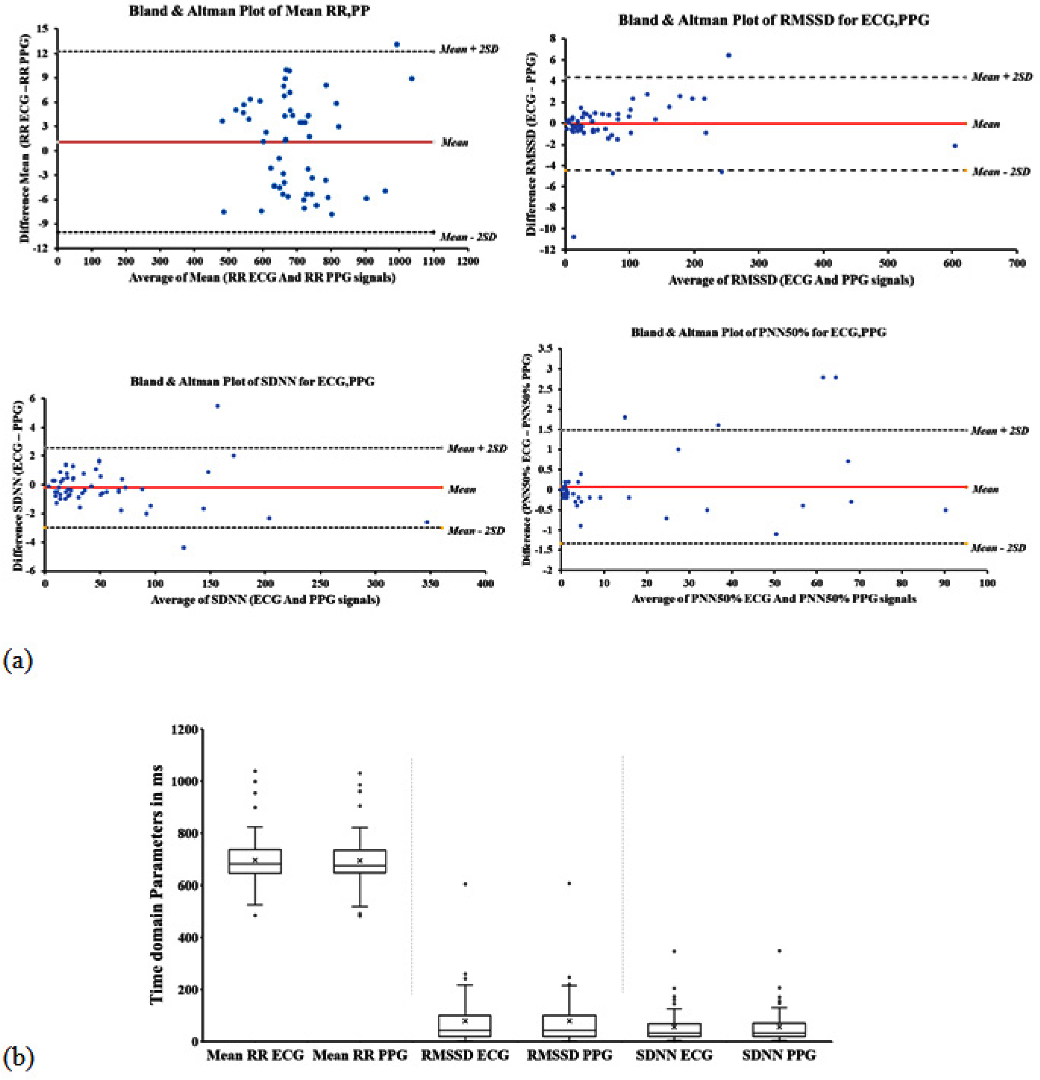

Fig. 1. (a) B&A Plot of the average values of the time-domain indices versus their differences, (b) Boxplot of time-domain indices

for every parameter in the Bland-Altman analysis (see Figures 1 and 2).

DISCUSSION

Two commonly used methods for measuring HRV are electrocardiogram (ECG) and photoplethysmography (PPG), which provide distinct measures of cardiac activity.

In this study, we compared HRV analysis using electrocardiogram (ECG) and photoplethysmogram (PPG) signals in a sample of patients. We examined the agreement and correlation between various HRV parameters derived from ECG and PPG signals, including frequency-domain and time-domain measures. Our findings suggest that both ECG and PPG signals can be used for HRV analysis.

Table 1. The linear parameter of the Heart Rate Variability for the two signals ECG, PPG

Variable	Electrocardiogram Signals	Photoplethysmogram Signals	Correlation coefficient(r)	*p*.value	CI 95%
Time domain					
Mean PP, RR (ms)	695.6 ± 112.9	694.4 ± 112.9	0.998	0.163	-0.46 to 2.66
Mean HR (Beats)	89.2 ± 13.5	89.5 ± 13.8	0.992	0.267	-0.72 to 0.20
RMSSD (ms)	76.1 ± 99.4	74.9 ± 92.2	0.995	0.894	-0.66 to 0.58
SDNN (ms)	54.3 ± 61.8	54.5 ± 62.1	0.999	0.321	-0.58 to 0.19
NN50	84 ± 144.6	89.4 ± 140.1	0.999	0.11	-0.8 to 0.08
pNN50 (%)	14.9 ± 24.8	12.8 ± 22.6	0.995	0.465	-0.13 to 0.27
Frequency Domain					
LF Power (ms^2)	1328.7 ± 3619.9	1350.3 ± 3590.50	1	0.056	-1.19 to 0.016
HF Power (ms^2)	2687.6 ± 6851.4	2610.9 ± 6852	1	0.452	-1.27 to 0.58
LF nu	36.4 ± 22.1	33.6 ± 24	0.999	0.084	-0.46 to 0.030
HF nu	63.2 ± 21.9	69.1 ± 21.8	0.998	0.633	-0.25 to 0.40
LF/HF	1.7± 5.3	1.6 ± 4.6	0.997	0.355	-1.17 to 0.32

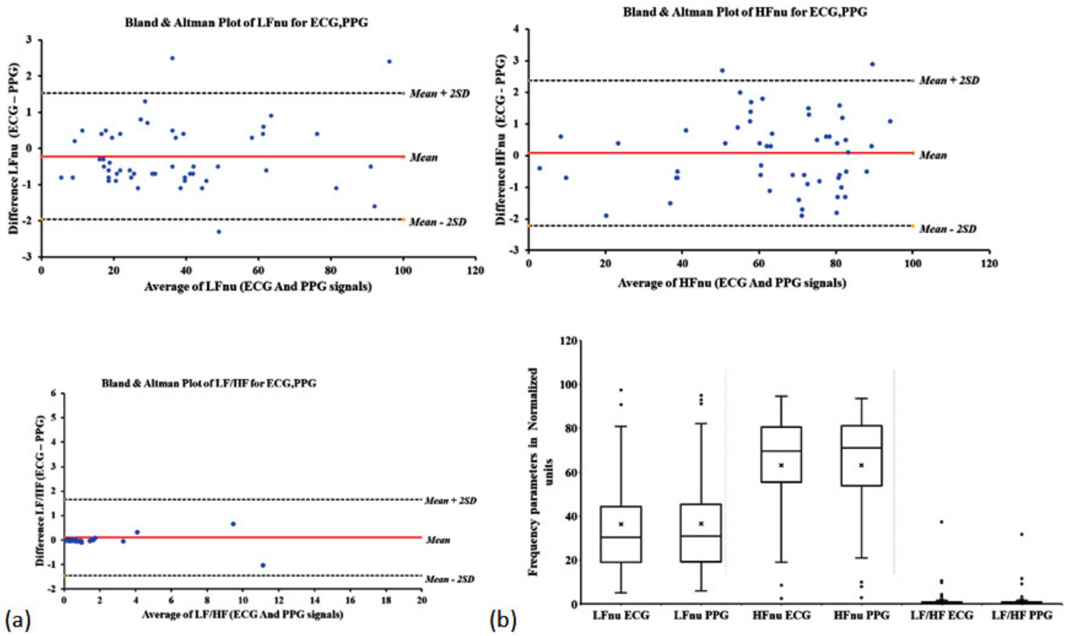

Fig. 2. (a) B&A Plot of the average of the Frequency-domain indices versus their differences, (b) Boxplot of Frequency-domain indices

According to the findings of the current investigation, the pulse interval variability (PIV) and heart rate variability provided by the electrocardiogram (ECG) and photoplethysmogram (PPG) signals show strong agreement for critically ill patients.

As shown in this investigation, the earlier results presented by C. Kiran Kumar, JA Heathers et al., Gil E et al, and Hayano et al., for healthy participants showed a significant link between pulse rate variability (PRV) and Heart rate variability (HRV). So, it established PRV as an accurate replacement for HRV, which has been utilized to get beyond the confounding effect of breathing of evaluation in HRV parameters[15 21 22 23]. Moreover, it may be impacted by exercise, stress, changes in hemodynamics, or adjustments in metabolism. In addition, HRV has additional issues with wire density, complicated morphology, drift, and adhesive electrode patches. While little research, including Constant I, 1999, has disputed the preceding consensus [24].

Clinically significant factors, including heart and respiratory rate and respiration-induced intensity fluctuations, can be measured using the PPG signal. The usage of PPG has risen in clinical monitoring in both research and practice due to recent developments and improvements in digital signal processing. Modern PPG sensors use inexpensive optoelectronic modules that operate in the red or infrared spectrum. Additionally, it is utilized to calculate cardiac output, endothelial and venous function, peripheral arterial occlusion, and pulse wave velocity. To highlight the most important results of the Bland-Altman technique, we collected the standard deviation and Bland-Altman plot for the major HRV indices corresponding to the ECG-PPG comparisons. The indices of both approaches showed significant agreement with one another. According to a study released by Wong Jih-Sen et al., all Heart rate variability (HRV) parameters and the corresponding Pulse rate variability (PRV) measures of both hands in each patient showed a significant agreement [25]. Therefore, we utilized the left side to provide a more accurate and reliable assessment and observed that the PRV and HRV had an acceptable level of agreement.

In contrast, several researchers discovered little concordance between PRV and HRV [24]. In various situations, various factors may affect how HRV and PRV differ. Due to physical differences, mechanical waves created in vessels for PRV and electrical waves originating from the heart [26].

A primary or secondary autonomic failure can be assessed using HRV and RVP, which are early indications of ANS dysfunction. They also aid in lowering the mortality and morbidity linked to cardiovascular diseases[27]. They are convenient, noninvasive techniques for diagnosing neurological conditions and for use in exercise interventional investigations and sports evaluation [28].

The current study has limits, as it was conducted on a group with a disease to be sure of the result. So, we would like to apply the same study to a large sample of people to predict their health status as part of a prospective study of various diseases, including hemodynamic diseases such as hypotension and real-time hospitalized patients, by using PVR parameters.

CONCLUSION

The study's findings suggest that PRV derived from PPG-Signal can be as effective as HRV in assessing the autonomic tone of the heart and predicting the health status of patients based on the comparison of calculated PRV parameters with HRV parameters in a group of patients with a known medical history.

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Conflict of Interest

There is no conflict of interests in association with the material presented in this paper.

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