

Comparison of Heart Rate Variability Indices Based on Seismocardiograms from Healthy Volunteers and Patients with Valvular Heart Diseases

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Abstract

Heart rate variability (HRV) is a physiological variation of intervals between consecutive heart beats that reflects the activity of the autonomic nervous system. This parameter is traditionally evaluated on the basis of electrocardiograms (ECG signals). Because seismocardiography (SCG) registers cardiac mechanical activity, it may be used in HRV analysis and the evaluation of valvular heart diseases (VHDs) simultaneously. In our study, our objective was to compare HRV indices in the time and frequency domain obtained from seismocardiograms (SCG signals) in healthy volunteers and patients with valvular heart diseases. The results of the HRV analysis indicate that there are significant differences between the HRV indices obtained from the seismocardiograms in healthy volunteers and patients with VHD. This shows the feasibility and validity of HRV analysis based on seismocardiograms in healthy volunteers and patients with VHD.

1. Introduction

Cardiovascular diseases are the most common cause of death worldwide and are a major concern for public health [1]. Valvular heart disease (VHD) is defined as any cardiovascular disease that affects any heart valve (aortic valve, mitral valve, pulmonic valve, and tricuspid valve) [2]. The main causes are rheumatic heart disease and aging [3–5].

VHDs are generally diagnosed with echocardiography, computed tomography, and magnetic resonance imaging [4]. However, these methods cannot be applied in outpatient monitoring [6]. An alternative approach is to apply seismocardiography (SCG) that records precordial accelerations with an inertial measurement unit (IMU) placed on a chest wall [6, 7].

Seismocardiography found applications in the diagnosis of several cardiovascular diseases, such as aortic stenosis [8, 9], coronary artery disease [10], myocardial infarction [11], atrial fibrillation [12], and heart failure [11].

Another popular application of seismocardiography is heart rate variability (HRV) analysis [13–16]. Heart rate

variability is a physiological variation of an interval between consecutive heart beats that reflects the activity of the autonomic nervous system [4, 17].

HRV analysis has traditionally been performed on cardiac intervals obtained from electrocardiograms (ECG signals) [13, 14, 17, 18]. The advantage of using seismocardiography is the availability of information on cardiac intervals, contractility, and the state of heart valves [6, 13, 14, 16–19].

The purpose of this study was to evaluate the differences between the HRV indices (time and frequency domain) derived from seismocardiograms in healthy volunteers and patients with valvular heart diseases.

2. Material and Methods

2.1. Datasets

We used two publicly available data sets that contain simultaneous recordings of electrocardiograms and seismocardiograms; Combined measurement of ECG, Breathing and Seismocardiograms (CEBS) publicly available on PhysioNet.org [20–22] and “An Open-access Database for the Evaluation of Cardio-mechanical Signals from Patients with Valvular Heart Diseases” (OAVHDDDB) published by Yang et al. in [6, 23].

The first data set consists of 20 recordings (b001–b020) of ECG signals, respiratory waves, and seismocardiograms (z-axis) acquired before playing the music in 20 volunteers who were awake and remained in the supine position on a bed during the signal registration. Each recording was acquired for 5 minutes with a sampling frequency of 5000 Hz with the Biopac MP36 data acquisition system (ECG signals) and the triaxial accelerometer LIS334ALH (ST Microelectronics) for SCG signals [20–22, 24].

The second data set consists of 30 simultaneous recordings of heartbeat intervals in ECG, SCG, and GCG signals acquired from 30 patients with valvular diseases admitted to the Columbia University Medical Center (New York City, NY, USA). The group of patients consisted of 14 female and 16 male subjects; all of them had aortic stenosis, 9 had tricuspid valve regurgitation, 5 had mitral valve

stenosis, 4 had mitral valve regurgitation, and no patient had aortic valve regurgitation.

During registration, each subject was asked to be awake and remain in the supine position, breathing normally. The effective acquisition time for each subject was between 298 and 603 seconds. The ECG and SCG signals were recorded with the Shimmer 3 ECG module (Shimmer Sensing, Dublin, Ireland) with a sampling frequency of 256 Hz (recordings UP-01 to UP-21) and 512 Hz (recordings UP-22 to UP-30) [6, 23]. Figure 1 presents raw ECG, SCG, and GCG signals obtained from subject 15 in OAVHDDDB.

2.2. Signal processing

The detection of heartbeats in ECG (lead II) and SCG signals (z-axis) in both data sets was derived as follows: the first step was the application of a Pan-Tompkins algorithm described in [25] to detect heartbeats in ECG signals. Then, the aortic valve opening (AO) waves (heartbeats in SCG signals) were detected as local maxima close to the QRS complexes in the ECG signals based on the approach described in [6, 14, 16]. The final step was calculating the interbeat intervals [6, 26].

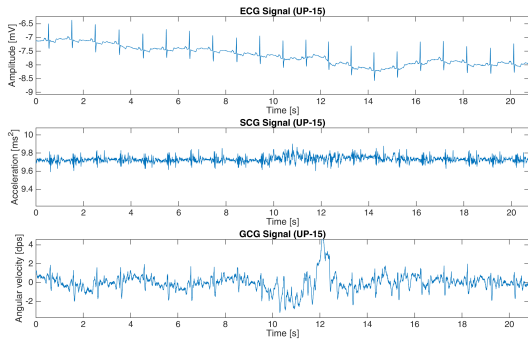


Figure 1. Raw ECG, SCG, and GCG signals from subject 15 in OAVHDDDB (first 20 seconds).

2.2.1. HRV analysis

HRV analysis was carried out according to the recommendations published in [17, 18]. We considered the following time and frequency domain indices: mean interbeat interval (AVNN), standard deviation of the interbeat interval (SDNN), root mean square of differences of successive interbeat intervals (RMSSD), the ratio of successive differences greater than 50 ms in all interbeat intervals (pNN50), the power of HRV signal in the very low frequency band (VLF), in the low frequency band (LF), in the high frequency band (HF), and the LF/HF ratio (LF/HF).

The very low frequency band was defined as 0.0033–0.04 Hz, low frequency band was defined as 0.04–0.15 Hz, and the high frequency band was defined as 0.15–0.4 Hz [17, 27]. The analyzes were carried out with the PhysioNet Cardiovascular Signal Toolbox [27, 28] and MATLAB R2021b (MathWorks, Inc., Natick, MA, USA).

3. Results

The results of HRV analyses on seismocardiograms expressed as the mean and standard deviation (SD) value of time domain and frequency domain HRV indices are shown in Table 1. The mean and standard deviation values of most HRV indices for patients with VHD are significantly different from those of healthy volunteers, except for AVNN and VLF. These differences were further evaluated by applying Student’s t-test for the significance level of 0.05. The results of the t-test are shown in Table 2.

The differences between the HRV indices in healthy volunteers and in patients with VHD shown in Table 2 are statistically significant for RMSSD, pNN50, HF, and LF/HF. These results confirm the findings related to Table 1, except for LF.

4. Discussion and Conclusions

We have performed HRV analysis on electrocardiograms and seismocardiograms in healthy volunteers and patients with VHD. The mean and standard deviation values of most HRV indices for patients with VHD are significantly different from those of healthy volunteers, except for AVNN and VLF. This observation was confirmed in the Student’s t-test, except for LF.

This indicates a strong influence of the presence of valvular heart disease on HRV indices, except AVNN (mean interbeat interval) and VLF, which was in line with [29, 30]. The similarities between the results of the HRV analysis in patients with VHD in our study and those reported in [29] prove that the HRV indices obtained from seismocardiograms are valid for patients with aortic stenosis and also for other VHD [14, 31].

The limitations of the study include the lack of comparison with the HRV indices obtained for ECG and GCG, the inability to evaluate the influence of various heartbeat detectors and other cardiovascular diseases, and the lack of commonly accepted recommendations on the annotation of changes in the morphology of the SCG and GCG signal related to valvular heart diseases.

In future studies, we consider comparing HRV indices derived from ECG, SCG, and GCG signals in healthy volunteers and patients with other cardiovascular diseases, larger and more diverse groups, and other heart beat detectors for SCG and GCG signals.

Table 1. HRV indices derived from SCG signals.

HRV index	Healthy		VHDs	
	Mean	SD	Mean	SD
AVNN [ms]	877.9971	101.5460	881.5849	156.4511
SDNN [ms]	76.7363	14.9097	113.0716	40.8948
RMSSD [ms]	76.5309	18.7695	160.9644	63.2959
pNN50	0.3263	0.1317	0.5499	0.2345
VLF [ms ²]	1088.9126	698.5854	1009.8038	849.8141
LF [ms ²]	1828.3777	1257.0929	2413.8259	2320.6393
HF [ms ²]	2811.1593	1358.4019	7275.5874	5670.2440
LF/HF	0.7160	0.4396	0.3177	0.1617

Table 2. Results of t-tests.

HRV index	h*	p-value
AVNN	0	0.9283
SDNN	1	0.0004
RMSSD	1	<0.0001
pNN50	1	0.0003
VLF	0	0.7313
LF	0	0.3083
HF	1	0.0012
LF/HF	1	<0.0001

* h=0 means no significant difference

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