Cardiovascular Function Analysis of Untreated Hypertensive and Normotensive Participants in Cardiopulmonary Exercise Test

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Abstract

Pulse wave analysis is a simple, low cost and non-invasive method for obtaining important information related to the cardiovascular system. This study aimed to investigate and compare the cardiovascular function between untreated hypertensive and normotensive participants before, during and after cardiopulmonary exercise test (CPET). Thirty participants (15 untreated hypertension and 15 normotension) were enrolled. Photoplethysmography (PPG), respiration signal and ECG were simultaneously collected while participants were conducting CPET. The second derivative of PPG (b/a, c/a, d/a, e/a and (b-c-d-e/a)), respiratory rate extracted by power spectrum analysis, pulse transit time (PTT) were analyzed. The results demonstrated that there were significant differences in e/a, respiratory rate, and PTT between two groups, while there were no significant differences in b/a and (b-c-d-e)/a before CPET. By contrast, the b/a, (b-c-d-e)/a and respiratory rate were significant higher after CPET. The c/a and d/a were significant lower in untreated hypertensive participants than those in normative participants after CPET. In addition, only respiratory rate was significant higher in untreated hypertensive participants than that in normative participants during CPET. The differences of vascular function and respiratory activity are found after CPET between untreated hypertension participants and controls. Additionally, we also found that there were significant differences in respiratory activity and the autonomic nervous function between two groups during CPET.

1. Introduction

Hypertension is the most prevalent chronic disease and a major predisposing risk factor for the cardiovascular morbidity and mortality. It has been associated with the progression of atherosclerosis and cerebrovascular disease [1, 2]. Based on the multi-factorial and complex nature, the underlying cause of hypertension cannot be accurately identified. Multiple physiological parameters should be monitored and measured in the clinical research.

Photoplethysmography (PPG) is an optical, simple and non-invasive measurement technique that can be used to monitor arterial pressure and compliance, and the change of blood volume in microvascular beds of peripheral tissues [3, 4]. Especially, the second derivative of PPG provided more information about both central and peripheral arterial factors [5, 6], and closely associated with cardiovascular risk indicators [7-9].

Some studies investigated the second derivative of PPG in patients with cardiovascular disease (CVD), however these results were controversial, and the mechanism was still unclear. Some studies reported that second derivative of PPG can be useful for assessment of vascular aging or for identification of arteriosclerotic disease [10, 11]. A study found that d/a was significantly related to the risk of metabolic syndrome and hypertension[12]. In contrast, there was no relationship between the second derivative of PPG and inflammation in middle-aged men with cardiovascular risks [8]. Moreover, a study showed that although the second derivative of PPG indices represented the changes of structure and function in arteries, they exhibited limited diagnostic significance for pathophysiological change in large arteries and small vessel diseases of brain [13]. Furthermore, few studies explored continuously and dynamically the second derivative of PPG in patients with CVD [14].

Cardiopulmonary exercise testing (CPET) was regarded as the gold standard for comprehensive assessment of exercise responses [15] and for diagnosis in cardiopulmonary functional capacity [1]. Some studies reported that CPET could predict and evaluate cardiovascular risk [1, 7]. Multiple physiological information (eg. PPG, respiration signal or ECG) in CPET should be investigated during CPET to provide novel opportunities for clinical research.

Therefore, based on the measurement of PPG, respiration signal and ECG, this study aimed to investigate and compare the cardiovascular functions in untreated hypertensive and normotensive participants before, during and after CPET.

2. Methods

2.1. Participants

Thirty participants (fifteen untreated hypertensive and fifteen normotensive participants) were enrolled from the Fuwai Hospital, National Research Center of Clinic Medicine for Cardiovascular Diseases, Beijing Rehabilitation Hospital and Beijing Haidian Hospital. There was no significant difference in age between two groups (Table 1).

Table 1 Characteristics of the study participants

	Untreated hypertension participants	Healthy participants	p value
No.	15	15	
Age	47±11.4	43±11.9	0.318
Height	169±6.1	164±5.9	0.006
Weight	78.6±9.7	64.8±8.6	0.003

Note： data are mean±SD.

2.2. Study protocol

The experiment was conducted at the key laboratory for CPET with comfortable temperature between 20-22℃. All the participants underwent a CPET （COSMED S. R. L.） on a cycle ergometer (COSMED) using an incremental protocol. The study protocol consists of 3-min rest on the cycle ergometer, 5-min no-load warming up and 5~10-min recovery. The incremental rate was 20-30W/min until individual exhaustion. The PPG, respiration signal (thoracic respiration and abdominal respiration) and electrocardiogram (ECG) were continuously recorded with the SOMNOscreenTM polysomnography device (SOMNOmedics GmbH, Randersacker, Germany) before, during and after CPET.

2.3. Data processing

The raw data (PPG [sampling frequency: 128Hz], respiration signal [sampling frequency: 32Hz] and ECG [sampling frequency: 256Hz]) were intercepted from continuous raw data by stages (before exercise, during exercise and after exercise) in consideration of data quality. Every stage included 15-30 continuous waveforms. The intercepted waveforms were then removed baseline wander correction and de-noise by wavelet decomposition.

2.4. Feature extraction and calculation

The raw data of PPG at three stages were performed by the Fourier fitting because many noise appeared when feature points of original waveform were directly extracted. The second derivative of PPG was obtained from Fourier fitting function with combining 3rd and 5rd. The fitting was computed by [16]: (Figure.1).

The raw respiration signals before, during and after CPET were analyzed by FFT. The respiratory rate was extracted as the basic frequency of power spectral density [16].

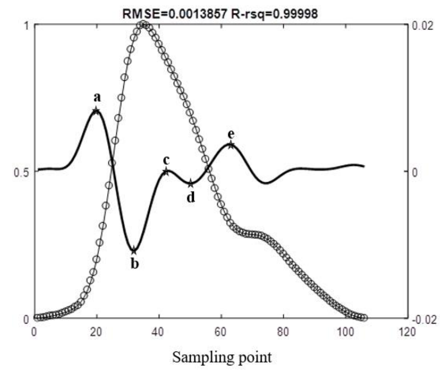

Figure.1 Typical PPG wave and the second derivative of PPG in a healthy participant at rest. These empty circles are the points of raw PPG, and the solid line connecting these circles is fitted by Fourier fitting.

2.5. Statistical analysis

All the data were presented as mean±SD. Independent-sample t-test was employed to conduct the significant differences in these parameters before, during and after CPET between two groups.

3. Results

3.1. Comparison of different methods of waveform fitting (Fourier, sum of sin, polynomial and Gaussian)

We compared four methods of waveform fitting in order to get an accurate waveform. Before exercise, the RMSE of Fourier fitting, sum of sin, polynomial and Gaussian was 0.0013857, 0.0016501, 0.029082 and 0.0053243, respectively. The results also showed that the Fourier fitting provided a better fit to this waveform during exercise (RMSE=0.00023419) and after exercise (RMSE=0.0013857). Therefore, the Fourier fitting was used to analyze this waveform.

3.2. Power spectral density analysis for

respiratory rate

The frequency spectrum was analyzed in all the participants before, during and after CPET (Fig. 3). There was significant difference in respiratory rate between untreated hypertensive participants and normotensive participants before, during and after exercise.

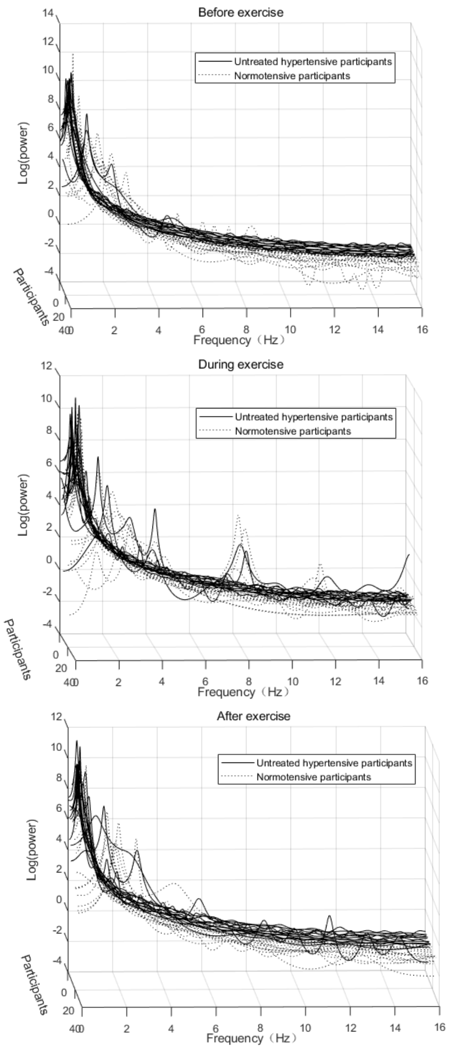

Fig. 3 Respiratory rate between untreated hypertensive participants and normotensive participants before, during and after exercise.

3.3. The different cardiovascular parameters between two groups before, on and after exercise

Before exercise, there were significant differences in e/a (0.22±0.11, 0.32±0.09, p-value=0.008), respiratory rate (0.82±0.62, 0.39±0.28, p-value=0.024) and PTT (32.41±2.38, 0.39±0.28, p-value=0.008) between untreated hypertensive and normative participants. During exercise, there was a significant difference in respiratory rate (1.18±0.84, 0.68±0.48, p-value=0.035) between two groups. In addition, c/a and d/a disappeared in two groups during exercise. After exercise, there were significant differences in b/a (-0.9±0.19, -1.06±0.19, p-value=0.03), (b-c-d-e)/a (-0.49±0.75, -1.15±0.59, p-value=0.013), c/a (-0.33±0.26, -0.07±0.19, p-value=0.005), d/a (-0.32±0.24, -0.14±0.17, p-value=0.026) and respiratory rate (0.92±0.66, 0.46±0.3, p-value=0.024) between two groups.

4. Discussion

The present study demonstrated that there were significant differences in e/a, respiratory rate, and PTT between two groups, while there were no significant differences in b/a and (b-c-d-e)/a before CPET. By contrast, the b/a, (b-c-d-e)/a and respiratory rate were significant higher after CPET. The c/a and d/a were significant lower in untreated hypertensive participants than those in normative participants after CPET. In addition, only respiratory rate was significant higher in untreated hypertensive participants than that in normative participants during CPET.

In this study, respiratory rate was a sensitive parameter to investigate the differences between two groups before, during and after CPET. There was significant difference in this parameter before, during and after exercise. A study found that it could predict cardiovascular disturbance, ventilatory control and pulmonary perfusion after acute myocardial [17]. The change of respiratory rate can also be a reflection of the cardiac autonomic control. The higher respiratory rate in untreated hypertensive participants reflected the disturbed autonomic control to some extent [17, 18]. Additionally, a study found that autonomic nervous system played key roles in modulating cardiovascular functions and in controlling BP, both at rest and in response to environmental stimuli [19]. Furthermore, a study reported that muscle sympathetic nerve activity significantly increased in response to exercise, together with significant increase in HR, respiratory rate and skin blood flow [20, 21]. Therefore, interaction of multiple physiological signals showed the different cardiovascular function between untreated hypertensive and normative participants.

5. Conclusion

The differences of vascular function and respiratory activity are found after CPET between untreated hypertension and normotensive participants. Additionally, during CPET, the difference of the autonomic nervous function and respiratory activity was found between two groups. Moreover, autonomic nervous function and respiratory activity were associated with vascular function and blood flow during exercise. This study also demonstrated that exercise can motivate more cardiovascular information to investigate the cardiovascular response between two groups, and can effectively assist in the diagnosis of hypertension.

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