The Real-Time Monitoring System of Blood Flow Velocity Using Doppler Ultrasound for Healthcare Application

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Abstract

Doppler ultrasound is a widely used and reliable non-invasive device for blood flow waveform measurement. However, the commercialized blood flow devices are usually in hospital with limited access for public, required monitoring by competent staff and not easily transported. The aim of current study is to examine the potential of a portable blood flow velocity (BFV) Doppler ultrasound system for healthcare application. The effects of visceral fat (VF) level, blood pressure (BP) level (hypertension), aging, regular exercise and exercise-trained programme toward blood flow waveforms and its indices are determined. The peak systolic (S1) velocity and resistive index (RI) are significantly higher (p<0.05) in older population who exercise regularly than who does not. There are significant differences (p<0.05) in the RI and velocity reflection index between normotensive and hypertensive groups. The S1 and peak diastolic (D) are decreased significantly (p<0.05) from normotensive to hypertension groups. Low VF group has significantly increase vascular elasticity than high VF group. In contrast, low VF group has decrease reflected wave velocity. Our findings have broad implication in prevention and monitoring of cardio-related health problem that possibly early detection by frequent measurement of BFV, BP and electrocardiogram using this portable device.

1. Introduction

Cardiovascular diseases are global health problem which leading cause of death worldwide [1]. Many of these diseases caused by hemodynamics dysfunction. This is because hemodynamics are mainly related to blood pressure and blood flow which circulate blood through cardiovascular system [1, 2]. Studies of blood pressure (BP) are well-established with variety of manual and automated measurement devices compared to blood flow velocities [2]. Therefore, it is opened new opportunity to develop economic, non-invasive, precise and rapid blood flow measurement system to better understanding the hemodynamics function and health of circulatory system.

Electrocardiogram (ECG) and BP devices are also diagnostic tools that routinely used in hospital to assess the hemodynamics function. There are many stand-alone and portable devices available for measuring the BP. Some of the BP devices have combination with other devices. Previously, we had developed the portable Doppler ultrasound which measuring real-time arterial blood flow velocity (BFV) with synchronized measurement of ECG and BP [3, 4]. Doppler ultrasound is a widely used and reliable non-invasive device for blood flow waveform measurement [3-6]. The commercially available ultrasonograph has limited access to public or healthcare due to its multifunction and complicated operating system. However, there is no ethic regulation involved that restrict only authorized staff could handle ultrasound system devices according to the Food and Drug Administration [3].

The goal of this study is to examine the potential of this portable BFV Doppler ultrasound system for healthcare application. We examine the effects of several factors such as visceral fat (VF) level, BP level, age and exercise toward blood flow waveforms and its indices. The reference data are expected for express-assessment, early screening of cardiovascular diseases and self-monitoring at home or in public facilities.

2. Materials and Methods

2.1 Subjects characterization and experimental design

In this study, two experiments are conducted independently. In the first experiment, 125 subjects are classified into two groups according to their VF level. Lower VF and higher VF groups are determined based on the standard proposed by North American Association for
the Study of Obesity [8]. For the hypertension analysis, all subjects are further classified into two groups based on their BP level; normotensive and hypertensive as described in the Sixth Seventh Report of the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure [1].

In the second experiment, we examine the effect of aging, regular exercise and exercise training on BFV. Study is performed in 202 subjects aged from 20 to 70 years subjects which normotensive, normal body mass index, not under medication and free of chronic diseases as assessed by medical history. The age range for young group is 20-44 years, while old group is 45-70 years. Both young and older groups are combined as a single group which labeled as general population. Exercise subjects are who performed regular aerobic exercise more than 3 times per week. We extend this analysis to further confirm the effect of exercise training on the BFV in a control study. The flow velocity of 8 selected sedentary subjects is measured before the exercise training. A training programme was performed for 4 weeks where subjects are required to exercise in average 3 times per week, 13-18 minutes per times for 3 km road running. The subjects are requested to make no changes to their diet or other daily routine within duration of the study. All subjects give their written informed consent to participate. This study is reviewed and approved by the Ethics Committee of Tokushima University Hospital.

2.2 Measurement system and data collection

We use developed portable measurement system to measure BFV. It consists of a probe, a Doppler signal discriminator (DSD), a transmitter, a receiver, an analog-digital converter and a laptop personal computer [5-7]. In the DSD, Doppler signal and 2 MHz fundamental frequency are detected synchronously. The low-frequency noise and harmonic noise are removed with band-pass filter of 100 Hz to 4.2 kHz.

Blood flow velocity data from common carotid artery are collected using the developed portable Doppler ultrasound measurement system with synchronized measurement of ECG and BP as shown in Fig. 1. The Doppler signal was taken out as a digital signal on real-time through 12bit-A/D converter by 10 kHz sampling frequency and saved it into the personal computer. The software used two circular buffers to store the samples at the input and output for stream data path respectively. The samples coming from an acquisition system were stored at a sampling frequency in the working buffer as sources for the signal processing. The processed signal was then stored in the rendering buffer, where it was available for rendering in the spectrogram. As post-processing, the Doppler signal is analyzed by fast Fourier transform (FFT) with the 25.6 ms Hanning window. FFT was repeated by using successive 256 data, which are given by shifting 128 data in turn as shown in Fig. 1A. The

Fig. 1: Blood flow velocity with its synchronized system and process flow of Doppler signal processing in the real-time monitor
spectrogram is processed by performing decimation using the frequency radix-2 FFT algorithm with a small discrete Fourier transform (DFT) to reduce the computation time. The 95% of the total power in Doppler encoded bandwidth (0 Hz to 5 kHz) is chosen as the peak frequency in each spectrum. To increase the efficiency, the decomposition of the DFT is optimized for real-valued signals, which known as real DFT computation. The signal then are analysed in pseudo 3-dimensional (3D) graph which is displayed the power spectrogram of BFV distribution (see Fig. 1B). The spectrogram as shown in Fig. 1C were extracted directly from pseudo 3D graph.

The envelope waveform of the flow velocity is extracted from this spectrogram using a threshold method and then computed using ensemble averaging technique (Fig. 1D) [5]. Blood velocities in common carotid artery (CCA) are characterized to five components waveforms: peak systolic (S1), second systolic (S2), insicura between systole and diastole (I), peak diastolic (D) and end-diastolic (d) velocities [3-7]. Then, these values were used to calculate the following velocity indices: the resistive index (RI) (1-d/S1), the velocity reflection index (VRI) (S2/S1-I) and the vascular elastic recoil (VEI) (1-I/D).

2.3 Statistical analysis

Data are expressed as means ± standard errors (SE). The differences between two groups are analysed using independent t-test. A p-value less than 0.05 are considered statistically significant. Statistical analyses are performed using SPSS for Windows software (SPSS version 21.0, USA).

3. Results

We observe the effects of regular exercise in improving BFV by considering the age (see Table 1). The S1 velocity is significantly higher (p<0.05) in older population who exercise regularly than who does not. As S1 show significant decrease, RI also increase significantly for older population who exercise regularly. The same pattern also observe in general population. The excersice training effect is further elucidate in a control study. The S1 is significantly higher after the exercise-trained. However, RI is significantly lower in the exercise-trained (see Table 1).

The effects of aging, BP and VF level on BFV are shown in Table 2. There are significant differences (p<0.05) in the indices RI and VRI between normotensive and hypertensive groups. The S1 and D are decreased significantly (p<0.05) from nomortensive to hypertension groups. The S1 and D velocities were significantly higher in subjects who has lower VF level then those who has higher VF. Low VF group also has significantly increase vascular elasticity than high VF group. In contrast, low VF group has decrease reflected wave velocity. Young and older groups show significant differences in S1 and D velocities. Older group has significantly decrease (p<0.05) VRI then young group.

4. Discussions and Conclusion

In the present study, we described the usefullness of arterial BFV function in prevention and management of cardio-related health problems using the developed portable measurement device. We measured the BFV and its indices after accounting for level of VF, BP, age and exercise.

Hypertension increases the risk of developing cardiovascular disease. This also supported by our study since the measurement value of velocity waveforms and its indices of hypertensive found to significantly reduced compared to normotensive. VRI and RI showed significantly different in hypertensive and normotensive

| Table 1: Regular exercise and exercise training enhanced blood flow velocity |
|-----------------------------------------------|-----------------------------------------------|
| General population | Older population | 4 weeks training |
| | Sedentary | Exercise | Sedentary | Exercise | Before | After |
| BFV (cm/s) | | | | | | |
| S1 | 81 ± 2 | 100 ± 4* | 69 ± 4 | 91 ± 7† | 86.6 ± 6 | 96 ± 7† |
| BFV index | | | | | | |
| RI | 0.73 ± 0.01 | 0.79 ± 0.01* | 0.75 ± 0.01 | 0.78 ± 0.02† | 0.85 ± 0.02 | 0.82 ± 0.02† |

* p< 0.05 indicates significant difference of variable between sedentary and exercise subjects in general population.
† p< 0.05 indicates significant difference of variable between sedentary and exercise subjects in older population.
† p< 0.05 indicates significant difference of variable between before and after 4 weeks exercise training.
(see Table 2). Previous study reported that VRI had significant different when comparing between diseased hypertension and control subjects [9]. Similar to our study, increased VF accumulation influences developing of hypertension (data not shown) [10]. Subjects with lower VF level, their BFV showed improvement (see Table 2). Thus, prevention and management of hypertension can be achieved by monitoring the BP together with BFV regularly and control the VF level. This self-monitoring achieved by monitoring the BP together with BFV.

Thus, prevention and management of hypertension can be improved whether in subjects with low VF level or increased VF accumulation influences developing of hypertension (see Table 2). Previous study reported that VRI had significant different when comparing between diseased hypertension and control subjects [9]. Similar to our study, increased VF accumulation influences developing of hypertension (data not shown) [10]. Subjects with lower VF level, their BFV showed improvement (see Table 2). Thus, prevention and management of hypertension can be achieved by monitoring the BP together with BFV regularly and control the VF level. This self-monitoring (i.e. BP, ECG and BFV) is able to perform in a single measurement step and easy to handle using this portable device.

Age is the strongest factor of the reduction of S1 peak [5]. S1 and D velocities were significantly decrease with aging as shown in Table 2. These reduction strongly related to the reduction of arterial compliance and its elasticity with age [3, 4]. The data demonstrated that exercise training improved cardiovascular function in control subjects after 4 weeks. More importantly, regular aerobic exercise improves the flow velocity waveform particularly for older subjects (see Table 1).

In conclusion, the VF level, high BP (hypertension) and age altered blood flow velocities. The flow velocities improved whether in subjects with low VF level or general and older population who regularly performed regular exercise. Our findings have broad implication in prevention and monitoring of cardio-related health problem that possibly early detection by frequent measurement of BFV.

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