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Measurement of Blood Flow Velocity Waveforms in the Carotid, Brachial and Femoral Arteries during Head-Up Tilt

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Abstract

The purpose of this study is to measure blood velocities in carotid, brachial and femoral arteries with synchronized measurement of electrocardiogram (ECG) during head-up tilt (HUT) using a developed telemetry measurement system. The velocity waveforms and ECG are continuously measured in six putatively healthy young subjects for 130 s during supine and 90 degrees HUT. From the measured peak systolic S1 and end-diastolic d velocities, we assess the velocity waveforms in 3 arteries by using an index of d/S1. The velocity waveforms, heart rate (HR), and blood pressure (BP) are assessed for 20 s at the stages of postural change. There is no significant change in the carotid index of d/S1, but there are significant increases in the brachial and femoral index. HUT induces increase in HR. However, BP does not change with tilt. A constant in the carotid index is due to the effect of cerebral autoregulation (CA) maintaining blood flow to the brain. In contrast, the index in the brachial and femoral is more influenced by venous pressure (VP) in postural change. In conclusion, this study demonstrates that synchronized measurement of blood velocity waveforms in carotid, brachial, and femoral in HUT using the telemetry measurement device is attainable.

Keywords: blood flow velocity waveforms, synchronized measurement, head-up-tilt, venous pressure, cerebral autoregulation

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1 INTRODUCTION

There are 2 kinds of non-invasive technique to measure blood flow, one is a Doppler ultrasound method and the other is an optical one. The Doppler ultrasound method is widely used to measure hemodynamic in blood vessels as arteries that exists in the deep place of the human tissue [1-5]. Analysis of the Doppler power spectrum and velocity waveforms is useful for assessing and diagnosing cardiovascular disease [6-11].

Rutherford et al. used the blood velocity waveforms: peak systolic S1, peak diastolic D and end-diastolic d velocities to diagnose carotid occlusive disease by discriminant analysis of the waveforms [10]. Yuhi et al. classified the blood flow velocity waveform of common carotid artery in cerebrovascular disease using the d/S1 value as an index of blood flow [9]. Nagamoto et al. used the index to investigate CCA blood flow during postural change in elderly nursing home residents using an ultrasonic quantitative blood flow measurement [8]. He suggested that carotid arterial blood flow velocity waveform could serve to predict some aspects of clinical outcome in old age [11].

Furthermore, postural changes involve large changes in hydrostatic pressure, which induces large charges in blood flow volume within the body [12]. The cardiovascular system in healthy individuals has the ability to rapidly respond to such ‘postural change’. Detection of abnormal cardiovascular responses to postural change has been proposed as an early sign of cardiovascular disease. Tilt tests, either the whole body or only above the waist, have been used to study the cardiovascular response to changes in blood flow volume [13-15].

However, synchronized measurement of blood circulation in the 3 arteries and ECG during postural change is difficult. Postural stress provided high level artifacts caused by relative movement of the vessel and ultrasound, and vibration of tissue, particularly measurement of blood flow in femoral artery [24]. In this study, we aim to investigate the changes of velocity waveforms in carotid, brachial, and femoral artery, HR and BP for 90 degrees HUT in 6 putatively healthy men subjects. For the present study, signal to noise ratios (SNR) are improved by ensemble average processing of signals.

2 METHODS AND MATERIALS

2.1 Subjects and experimental protocol

Six sedentary male subjects (aged 23±2 years; body mass index, 20±2 kg/m^2) participated in the study. Each subject was medically examined before the study to ensure their capability of participating in the performed postural changes. All the subjects were normotensive, and free of overt chronic diseases as assessed by medical history. They gave their written informed consent to participate. This study was approved by the ethics committee of Tokushima University Hospital

The tilt test was performed from initial supine (Supine 1) to 90 degrees HUT and continuously placed back to supine (Supine 2). Tilt table provided a footboard and chest harness. The subjects were standing on the footboard of the tilt table. The test duration was 30 s for Supine 1, 30 s for HUT and 30 s for placed back to Supine 2. The tilt response was produced by manually rotating a hinged table by 90 degrees in 20 s. The subject was asked to lie supine on the table for at least 5 minutes of quiet rest to obtain a stable BP and HR. When all parameters were stabilized, the test was initiated. It was repeated two times in each subject with similar procedures.

The test operated in a comfortable room with a temperature range of 19-24℃. The subjects were instructed to refrain from eating and ingesting caffeine or alcohol for at least 2 hours before the measurements.

2.2 Synchronized measurement system

Synchronized measurement system of blood flow velocities, ECG and BP had been constructed in our laboratory. The blood flow velocity measurement system was based on Doppler ultrasound technique. In the study, blood velocities in carotid, brachial, and femoral arteries were measured simultaneously using telemetry system with real-time monitoring.

The telemetry measurement system of blood flow velocity in common carotid artery with synchronized measurement of ECG had been developed as reported in the previous study [3, 17]. We reported that our telemetry system had enough performance to obtain accurate data for estimation of blood circulation during exercise in both aerial and aquatic environments [3-5, 17]. The telemetry device for measurement of blood flow velocity distribution consisted of a probe, a Doppler signal discriminator (DSD), a transceiver, an analog-digital (A/D) converter board and a lap-top personal computer (PC) [3, 17].

The probe was designed by two piezoelectric transducers (PZT) with a diameter of 15 mm, where one was for transmitting ultrasound and the other was for receiving the echoes using continuous-wave (CW) ultrasound. It was designed for particular use in the measurement of blood flow distribution during physical exercises [3, 17]. The maximum intensity of ultrasonic output, called ISPTA index was approximately 8.1mW/cm^2. The ultrasonic output was safe for the human tissue.

The probes were attached to the skin with an insonation angle of 50 degrees, and were fixed with band wound around the measurement sites. The measurement sites were located between the sternocleidomastoid muscle and the throat at a level between the fourth and fifth cervical vertebrae in the left common carotid artery, approximately in the middle of the upper arm in the left brachial artery, and on the upper third of the thigh in the left superficial femoral.

2.3 Data collection

The Doppler shifted frequency of reflected signals included a low-frequency noise and a harmonics noise. The noise was removed by band-pass filter of 100 Hz to 4.2 kHz in the DSD. From that range of the frequency, blood flow signals were acquired through 16 bit A/D converter (Interface, CBI-360116TR, Japan) by 10 kHz sampling frequency and analyzed by fast Fourier transform (FFT) of 256 points with a Hanning window. The relation of blood flow velocity (V_d) and Doppler shifted frequency (f_d) was given by the classic equation: $V_d = cf_d/(2f_0\cos\theta)$, where, c=1540 m/s is the sound speed in human tissue, f_0 is an irradiated ultrasound frequency and θ= 50 degrees is the insonation angle.

With synchronized triggering of ECG signal at 12.8 ms intervals, blood flow velocities were precisely measured. ECG data was measured using commercially available MEG 2100 (Nihon Kohden, Japan). The ECG electrodes were attached on the chest using standard three-lead recordings.

The synchronized measurement of blood flow velocity spectra in 3 arteries and ECG was continuously performed for 130 s with real-time monitoring. All data was saved in laptop PC for further analysis. Heart rate was measured from R-R intervals of ECG. The data (blood flow velocities and HR) was analyzed from the selected consecutive 20 s in the supine and HUT stages.

Systolic, diastolic and mean BP were collected at the right brachial artery every twenty seconds using the automatic blood pressure monitor with Intellisense HEM-757 (Omron, Japan) that measured once for every postural change. Mean BP was calculated from (Systolic + 2*Diastolic)/3.

2.4 Data analysis

Ensemble average of consecutive 20 s of envelope velocities was used to measure peak systolic S1 (maximum) and end-diastolic d (minimum) velocities at every stage of postural change. The envelope velocity (Vp) was extracted from spatial velocity spectra using a threshold method. The data was analyzed by the same operator. In the study, we used the d/S1 as an index of blood flow to assess the hemodynamic change during HUT postural change. The SNR was improved by the ensemble average of the signals processing.

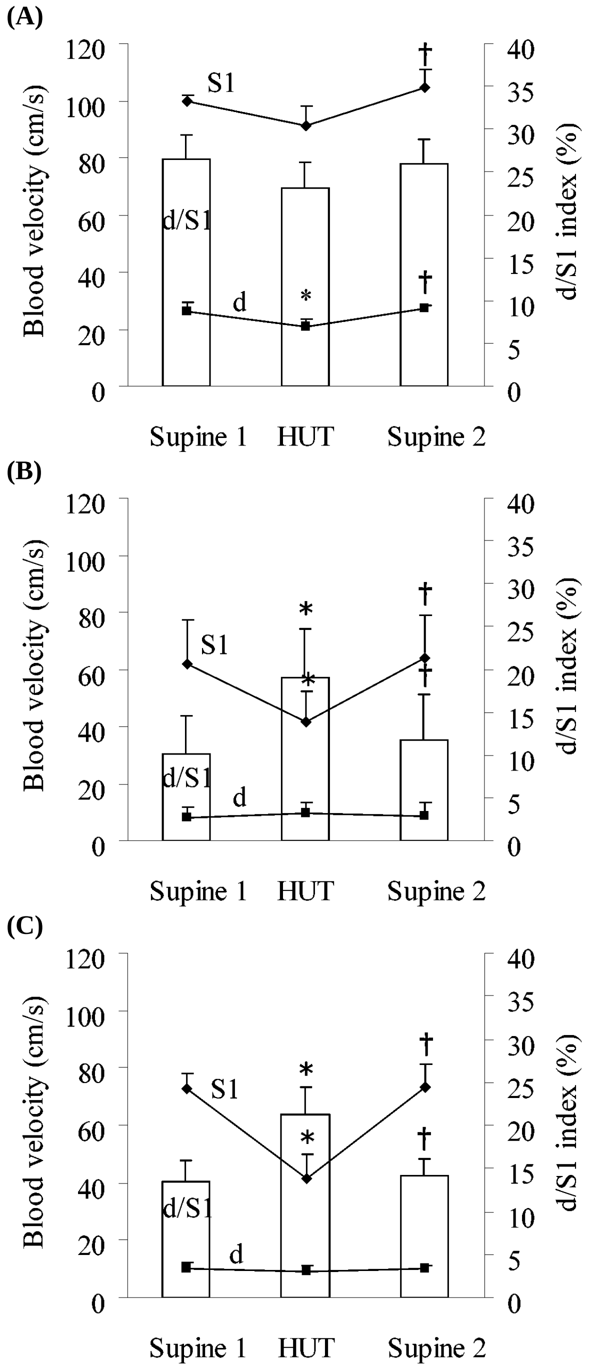

Figure 1: Line and bar graph represent the change blood flow velocities and d/S1 index in carotid (A), brachial (B) and femoral (C) arteries to HUT, respectively. *P<0.05 vs. Supine 1, †P<0.05 vs. HUT. Data are mean and SD.

2.5 Statistical analysis

We used multivariate analysis to determine any significant effects on HUT. The pairwise multiple comparisons in three stages of postural change (Supine 1, HUT and Supine 2) were determined using Tukey's post-hoc test. The significance level (P) was set at 0.05. All data was reported as means and ± standard deviation (SD). Statistical package for the Social Sciences (SPSS) version 13.0 for Windows was used for statistical analysis of the data.

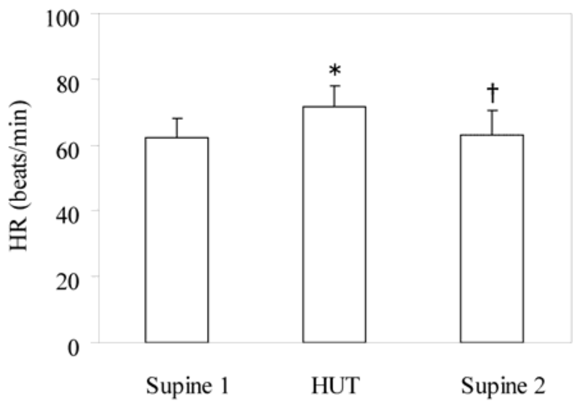

Figure 2: Heart rate changed during HUT. *P<0.05 vs. Supine 1, †P<0.05 vs. HUT. Data are mean and SD.

3 RESULTS

The results were presented in two sections: as the changes of 3 arteries blood flow velocities and its d/S1 index to tilt, and as the changes of HR and BP to tilt.

3.1 Blood velocity in carotid, brachial and femoral arteries during HUT

As shown in Fig. 1(A), d velocity in carotid changed significantly to tilt (P=0.002, HUT effect). Although S1 velocity significantly increased after posture back to supine (P=0.006), there were no significant changes in waveform index of d/S1 (P=NS; no significance, multivariate analysis). Fig. 1(B) and (C) indicated that S1 velocity in brachial and femoral changed significantly to tilt (P=0.001 and P<0.0001, respectively, HUT effect), therefore the waveform index decreased significantly (P=0.002 and P=0.001, respectively, HUT effect). However, there were no HUT effects on d velocities in brachial and femoral arteries.

3.2 Changes of heart rate and blood pressure

Heart rate markedly increased during HUT posture as shown in Fig. 2 (P=0.047, HUT effect). However, as shown in Fig. 3, we could not find any significant change in systolic, diastolic and mean BP to tilt (P=NS, multivariate analysis).

4 DISCUSSIONS AND CONCLUSION

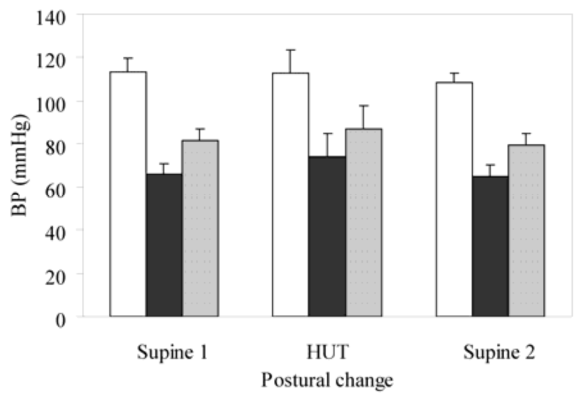

Figure 3: Systolic (□), diastolic (■) and mean (■) BP responses to HUT. Data are mean and SD.

The results of the present study demonstrated that when blood velocity waveforms in carotid, brachial and femoral arteries were compared, the change of d/S1 index was different in carotid artery as compared to brachial and femoral artery during HUT posture. The index was constant in carotid and increased in brachial and femoral artery.

From statistical multivariate analysis, there was only a tendentious decrease in S1 velocities which made no significance. Head-up tilt only affected the decrease in d velocities, thus we could not find the significant level in the carotid index of d/S1. In the brachial and femoral index, because of greater decrease in S1 velocities and no significant change in d velocities, both indices significantly increased to tilt. Although, both S1 and d velocities in carotid artery decreased to tilt, only d velocities had significantly decreased. The decrease of d velocities could be explained by the increase of peripheral resistance during HUT. Baroreflex disengagement occurs when humans stand, leading to an increase in sympathetic vasoconstrictor tone, which may lead to an increase in peripheral resistance [18].

Standing posture induced larger change in the brachial

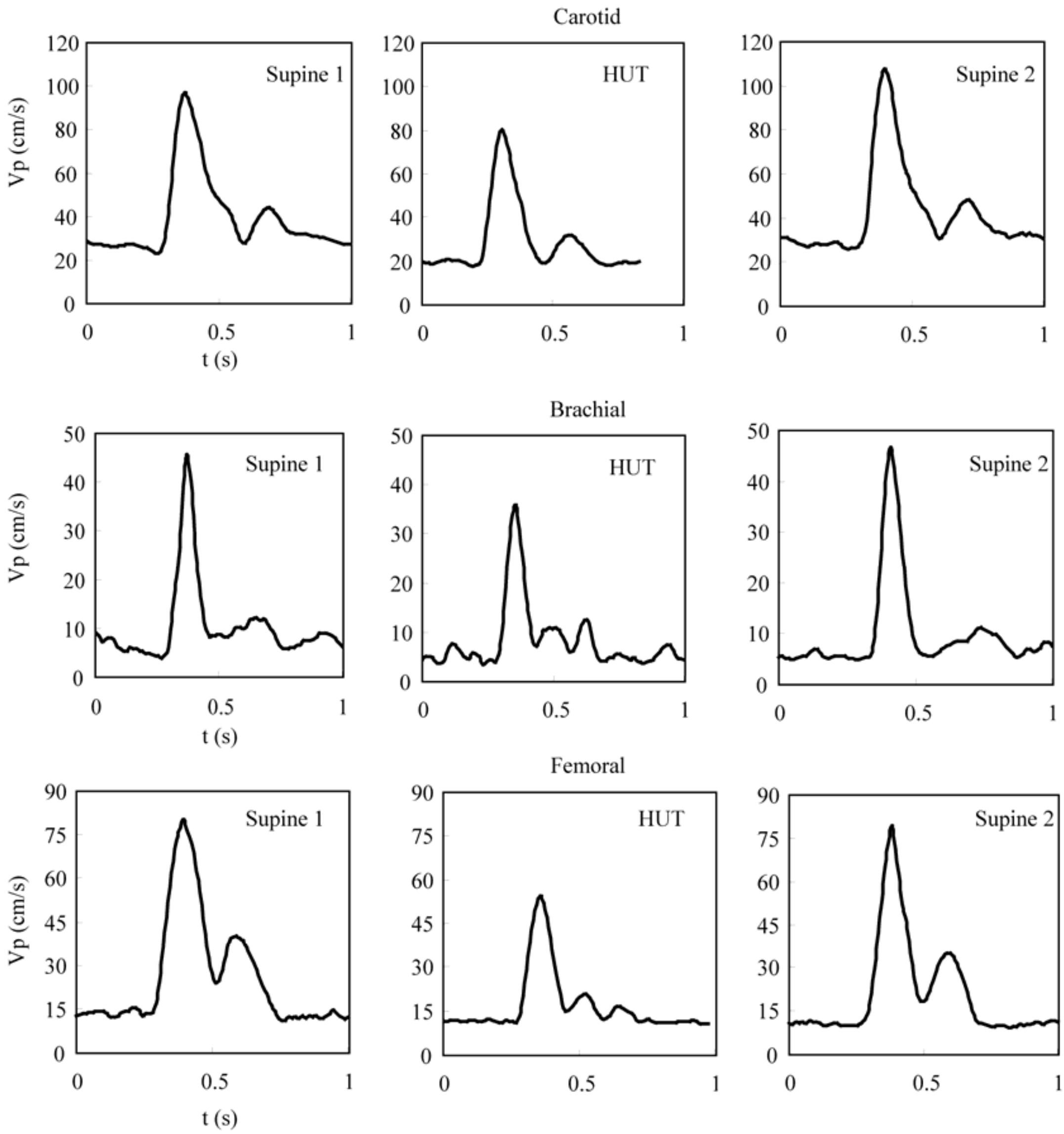

Figure 4: Ensemble average of consecutive 20 s of blood flow velocity waveforms in carotid, brachial, and femoral arteries in one subject (aged 23 years). Note that inverse flow components were not taken into account for analyzing blood flow spectra in femoral artery.

and femoral arteries compared to carotid artery [19]. The lesser change of blood flow velocities in carotid was considered to be the influence of CA. CA refers to the ability in the brain to maintain constant blood flow despite changes in cerebral perfusion pressure [20-22]. Cerebral blood flow (CBF) was depended on baseline arterial blood pressure (ABF) and CBF. If blood flow changed significantly with either an increase or a decrease in ABF, CA was said to be impaired. If blood flow was maintained at or near the baseline level, despite ABP changes, CA was said to be intact [20-22]. Owing to the function of CA in brain, S1 velocities at the resting were consequently and consistently higher in carotid. Approximately 70 % of the blood flow to the brain comes from the common carotid artery, thus regulation of flow immediately after a postural challenge was highly regulated and very important to maintain function [16].

Then, the greater changes of blood flow velocity in femoral were considered to be the influence of VP. Since compliance was high, the vein had stored 70-80 % of the amount of circulation blood, and was called capacitance vessel. VP would be strongly influenced by gravity due to its low pressure. Therefore, blood would be stored in the vein located further below the heart in the state of a standing position. Furthermore, changes in the femoral artery might be expected to be just the opposite of the carotid artery, with large changes in blood flow to assist in maintaining blood flow to the brain [22].

In response to postural changes, young subjects rely essentially on cardiac adaptation, i.e. a marked increase in HR [23]. Although, other findings reported that postural changes induced significant increase in diastolic and mean BP [13], our results showed that there were non-significant changes of BP to HUT.

It was difficult to determine the other differences of blood velocity waveforms in 3 arteries during HUT posture. Although, the results of the present study were limited by a small number of subjects, the main finding of this study was the simultaneous measurement of blood flow velocities in carotid, brachial and femoral arteries, and ECG. As indicated in Fig. 4, the measurement device had enough performance to obtain accurate information of blood circulation. The accurate estimation of blood flow spectra using Doppler ultrasound also depended on the insonation Doppler angle because it must be taken into account when calculating blood flow velocity from the Doppler shift frequency. However, the estimations were not a sensitive function for the index of d/S1 due to the independence of the insonating angle and it being dimensionless. The telemetry measurement system of blood flow velocity in common carotid and brachial arteries with synchronized measurement of ECG had been successfully developed as reported in the previous study [3-17]. The studies reported that our telemetry system had enough performance to obtain accurate data for estimation of blood circulation during exercise in both aerial and aquatic environments [3-5, 17].

Another interesting observation was that since we only acquired information on common carotid artery, the results could be blunted due to the nature of this artery, where the blood was carried to various regions of the head (e.g. eye, face, brain). Perhaps the monitoring of the internal carotid artery alone would provide a more valid information on how blood flow to the brain was affected during a postural change such as HUT.

In conclusion, a 90 degrees HUT produced larger changes of blood flow in brachial and femoral, and of HR. The constant of d/S1 in the carotid artery was expected to be the effect of CA to control blood flow to the brain. In contrast, the larger changes of blood flow in the brachial and femoral was greatly influenced by VP in the standing posture. Thus, this study demonstrated that synchronized measurement of blood flow velocity waveforms in carotid, brachial, and femoral in HUT using our telemetry measurement device was attainable. This method could prove to be a useful tool for investigating cardiovascular disease risk with further research and development.

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