Assessment of First Derivative of Doppler Blood Flow Velocity in Vascular Aging

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Abstract— **The aim of this study is to determine the first derivative of blood flow velocity (FDBFV) in common carotid artery (CCA) in order to evaluate cardiovascular functions. The extracted derivative of the velocity is suggested the acceleration waves which able to provide an aging index (AGI) in the cardiovascular system. In the study, acceleration wave derived from FDBFV consist of *a, b, c, d, e* and *f* waves which represent the initial positive, early negative, re-increasing, late re-decreasing, diastolic positive waves and diastolic negative waves, respectively. The FDBFV waveforms of 227 healthy volunteers are statistically analyzed in the study. Pearson's correlation analysis is used to determine the relationship between all variables and factors on the selected hemodynamic data. In the study, there are significant difference (r=0.727, p<0.001) of AGI in FDBFV. We found that f wave in FDBFV waveform shows strong correlation (p< 0.001) to blood pressure. In conclusion, the potential of FDBFV in CCA is an effective method to evaluate the vascular aging.**

Keywords— **Common carotid artery, vascular aging and cardiovascular.**

I. Introduction

Pulse wave or blood flow analysis is well known as an important tool to evaluate the arterial stiffness, hypertension and atherosclerosis [1]. There are two 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 exist in the deep place of the human tissue.

Analyses of the Doppler power spectrum and velocity waveforms are useful for assessing and diagnosing cardiovascular disease. Theoretically the first derivative of the velocity of the Doppler wave represents the acceleration of the flow [2]. Second derivative of photoplethysmogram (SDPTG) produces acceleration wave which has the same output as FDBFV. However, the signal produced in SDPTG is not contained the f wave. The aim of the study is to investigate the determinants of first derivative of Doppler blood flow velocity in CCA to evaluate the cardiovascular functions affected by gender, blood pressure and body fat.

II. Methods and Materials

A. Measurement System

In this study, blood velocity data from the CCA were collected using the developed wireless measurement system. This system was developed to measure the blood velocity spectra with synchronized measurement of electrocardiograph and blood pressure (BP). Measurements of blood flow velocity (BFV) were noninvasively detected by using Doppler ultrasound method [3-7]. The measurement system consists of a probe, a Doppler signal discriminator (DSD), a transmitter, a receiver, an analog-digital converter and laptop personal computer. Data were transmitted using 315 MHz FM/FSK transmitter which have 28.8 kbps and ~0.5 mV/m for transmission speed and output respectively [3].

The system has been developed to a miniaturized Doppler blood flow velocity (BFV) measurement device to monitor BFV at CCA with synchronization measurement of electrocardiogram and blood pressure at brachial artery [5].

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B. Data Analysis

An anthropometric parameters were measured to all subjects: weight, height, body mass (BMI), body fat, visceral fat level and waist circumferences. Body weight (kg), body fat (%) and visceral fat level were measured by using the InnerScan body composition monitors (InnerScan BC-610, Tanita, JP). These devices use bioelectric impedance analysis to monitor multiple indicator of overall health. A stadiometer (THP-DA, Ogawa Iriki, JP) was used to measure the height and the BMI (Body Mass Index), an indicator of obesity was obtained by dividing the body weight by the square of height (kg/m^2).

The systolic blood pressure (SBP) and the diastolic blood pressure (DBP) were measured for the left brachial artery using an automatic blood pressure monitor (Tango, SunTech Medical, US). The mean blood pressure (MBP) and the pulse blood pressure (PP) were calculated using DBP + (SBP−DBP)/3 and SBP−DBP, respectively.

Fig. 1 represents the envelope waveform of the flow velocity was extracted from the spectrogram using a threshold method. The velocity envelope was computed using an ensemble averaging technique for 30 consecutive cardiac cycles. The averaged velocity waveforms were used to identify characteristic points in the blood velocity waveforms and to calculate blood velocity indices [5-7]. Acceleration waveforms as illustrated in Fig. 1 are acquired from derivative of the averaged velocity waveform.

The FDBFV consists of six waves, represented a, b, c, d, e and f as the initial positive, early negative, re-increasing, late re-decreasing, diastolic positive waves and diastolic negative waves, respectively. To describe the FDBFV components quantitatively, the height of each wave was measured from the baseline as illustrated in Fig. 1. Using six waves of FDBFV, we calculated b:a, c:a, d:a, e:a and f:a ratios to use for statistical analysis.

According to the previous study by Takazawa et al, aging index (AGI) was defined as (b-c-d-e)/a [8]. The AGI was considered as markers of the dispensability of large arteries, the intensity of reflected wave from periphery and vascular aging. As f wave can be measured clearly, we proposed to insert f value to the equation to evaluate AGI for further analysis.

C. Statistical Analysis

Data were expressed as mean ± standard deviation (SD). To provide an overall view, Pearson's correlation analysis was performed to confirm the relationship between all outcome variables and factors. Significant differences in the outcome variables of men and women were evaluated by Student's t-test analysis. The correlation coefficients (r) of all variables with age were determined after compensating for the effect of exercise and gender by performing partial correlation analysis. Multiple regression analysis was performed to assess linear associations between aortic pulse wave velocity, FDBFV indexes and BP parameters, and determinants of age, gender, body weight, body fat, HRs and BP parameters. The significance level p was set to 0.05.

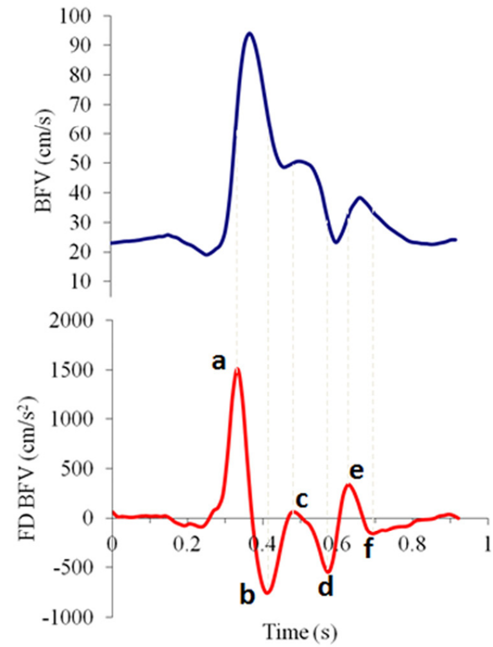

Fig. 1: An envelope velocity waveform and its first derivative of BFV

III. RESULTS

The study was performed in a total of 227 healthy subjects (138 male, 89 female) between 20 and 70 years old which were normotensive. The measurement was taken from each subject for two minutes to detect the cervical arterial blood flow velocity at rest sitting posture.

Table 1. Anthropometric data of gender difference

Parameter	Female (n=89)		Male (n=138)	
Heart rate (bpm)	73.6	±10.0	72.2	±11.0**
Height (cm)	157.7	±4.9	169.8	±6.4**
Weight (kg)	51	±7	64	±10**
BMI (kg/cm2)	20.3	±2.3	22.3	±3.2**
Systolic BP (mmHg)	114.8	±12.1	121.3	±11.7**
Diastolic BP (mmHg)	71.1	±8.9	74.7	±10.4*
Mean BP (mmHg)	85.7	±9.3	90.2	±10.3*
Pulse BP (mmHg)	43.7	±8.1	46.6	±7.5*
Body fat (%)	27.8	±4.6	17.4	±6.1**
Visceral fat (level)	2.8	±1.5	6.3	±4.8**

Significances indicated as *p<0.05, **p<0.001

Table 2. Gender-related differences in FDBFV ratio data

Ratio/ Index	Female (n=89)		Male (n=138)	
b:a	-0.379	±0.128	-0.420	±0.154*
c:a	-0.002	±0.064	-0.006	±0.064[NS]
d:a	-0.329	±0.082	-0.325	±0.110[NS]
e:a	0.129	±0.055	0.150	±0.058*
f:a	-0.104	±0.025	-0.119	±0.032**
(b-c-d-e+f)/a	-0.273	±0.241	-0.354	±0.277*
(b-c-d-e)/a	-0.169	±0.231	-0.234	±0.270[NS]

Significances indicated as *p<0.05, **p<0.001, NS: not significant.

A. Gender Difference

Table 1 shows the gender differences in body height, body weight and hemodynamic variables within 227 selected subjects. As the most pronounced SBP was lower in women than in men (p< 0.001). We also found that carotid blood velocities and its velocity indices had the significances for gender difference (p< 0.05).

Table 2 represents the gender-related differences in FDBFV ratio data. There was remarkable gender difference in flow velocities ratio expected for c:a, d:a and (b-c-d-e)/a. it is shown that the FDBFV indices were significant different between men and women (p<0.05) and (p<0.001).

B. FDBFV Waveform Change with Age

Table 3 show that there are age-related increases in *b:a* and *f:a* ratios and decreases in *c:a*, *d:a*, and *e:a* ratio. The equation of *(b-c-d-e)/a* was defined as SDPTG aging index and age [9]. The parameter used by K. Takazawa et al. has been used in this study to measure AGI. Although the index value after considering the *f* wave (*b-c-d-e+f)/a* (r=0.727, p<0.001) was slightly lower than *(b-c-d-e)/a* (r=0.737, p<0.0001), but there were no large difference has been observed.

C. Multiple Regression Analysis

Table 4 indicates the relationship between FDBFV ratio parameters and correlation coefficients. Stepwise regression analysis show that e:a ratio was significantly correlated with age parameter. In addition, f:a ratio was significantly correlated with gender and heart rate whereas significantly high correlated with SBP (p< 0.001).

Table 3. Acceleration wave changed with age

Ratio	r	p
b:a	0.729	<0.0001
c:a	-0.269	=0.004
d:a	-0.583	<0.0001
e:a	-0.236	=0.009
f:a	0.261	=0.005
Index		
(b-c-d-e)/a; (AGI)	0.737	<0.0001
(b-c-d-e-f)/a	0.727	<0.0001

AGI: Aging Index, r: correlation coefficients, p: significant level.

Table 4. Multiple regression analysis of acceleration wave

Ratio	Parameter	Beta	t value	p value
b:a	Age (years)	0.792335	12.73005	2.99E-22
	Sex (F=0, M=1)	-0.2119	-2.86214	0.005176
	Weight (kg)	-0.19292	-2.53153	0.012998
c:a	Heart rate (beats/min)	-0.32299	-3.50322	0.000706
	Age (years)	-0.43414	-3.88726	0.000189
	Body fat [%]	0.224317	4.455863	0.015892
	MBP (mmHg)	0.239387	2.119365	0.036695
d:a	Age (years)	-0.56621	-7.2255	1.19E-10
	PP (mmHg)	0.270581	3.452923	0.000827
e:a	Age (years)	-0.23619	-2.39392	0.018593
f:a	SBP (mmHg)	0.507395	5.336086	6.44E-07
	Sex (F=0, M=1)	-0.42695	-4.53076	1.71E-05
	Heart rate (beats/min)	-0.25036	-2.82728	0.005725

MBP: mean blood pressure, SBP: systolic blood pressure, PP: pulse pressure, Beta: standardized coefficients, t value and P value for used to compare mean values arterial blood flow acceleration analysis with the measured variable ratio level.

IV. DISCUSSIONS

The major finding in this paper is to determinant of the first derivative of the blood flow velocity effected the aging index in the vascular aging. This outcome of the flow velocity waveform may contribute to the improved of cardiovascular risk and autonomic nervous system.

FDBFV quantifiers of the peripheral arterial pressure dynamics in an early and late systolic period have a different relationship to simple clinical variables. The correlations between gender of an early (b:a, c:a) and late (d:a, e:a, f:a) systolic phase were negative and positive respectively and the strength of this correlation increased gradually from early to late systole. The correlation has been supported to the SDPTG analysis between age and descriptor [15].

Each wave ratio had significant parameters related changes. a and b waves are included in the early systolic component where the effect of reflection wave is less. Therefore, the b:a ratio may reflect the large arterial stiffness. The b:a ratio was higher in women than in males which is similar data showing in Takazawa et al. The epidemiological study on pulse wave velocity showed that pulse wave velocity in women was higher than that in men [16]. Therefore, it was assumed that the body structure (i.e., relatively short limbs and small diameter of ascending aorta) in women contributed to the result. In our study, women were also shorter than the male in height.

To further investigate the evaluation of the vascular effect of aging by FDBFV, we calculate the acceleration wave changes in the age and multiple regression analysis which is currently used to identify the aging index [8]. By considering f wave the AGI in the FDBFV we found that, there were a relationship between age and acceleration of the blood flow in CCA. These observations support the validity of the current vascular aging index [17].

The FDBFV was correlated with the parameters as shown in the Table 4. From the observation, there were significant correlation with age in the e:a ratio which has been supported in the SDPTG analysis[8, 16]. The correlation was observed in systolic blood pressure, gender and heart rate in f:a ratio. Systolic blood pressure and heart rate had significant and independent influences on FDBFV indicated. This is because the FDBFV dependent not only in the arterial properties but also in the left ventricular function [17].

A determinant of wave acceleration was found by multiple regression analysis of carotid artery. In addition, value of f shows the correlation between the systolic and diastolic pressure significantly. The measurement of the wave acceleration carotid shows the usefulness of the measurement system blood flow. Besides that, monitoring the parameters of arterial blood flow is very important for the biological information and healthcare purpose.

V. CONCLUSION

These data extend recent findings on the relationship between FDBFV and AGI measurement. We showed that f wave in the FDBFV indicate the missing biological information in previous method. Hence, further study need to be perform to investigate the correlation of cardiovascular risk in FDBFV.

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