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Non-Invasive Measurement of Arterial Stiffness Using the Analysis of Oscillometric Waveform during Cuff-Inflation

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Abstract

Background

We developed the new method which is measured arterial stiffness simultaneously with blood pressure by oscillometry during cuff inflation, and evaluated usefulness of the index as a marker of cardiovascular disease.

Methods

The cuff pressure pulse waves during linear cuff inflation were extracted by blood pressure measurement device in 97 outpatients with hypertension. The paired values of the cumulatively added cuff oscillation amplitudes and the corresponding cuff pressures are stored in the device during the measurement. Each of the cumulative addition value was exchanged to the ratio of total addition, and the cuff pressures, P0 and P1, corresponding to the ratios, R0 and R1, respectively, were used for calculation of the Cuff-Oscillometric Stiffness Parameter (CSP) which was defined as ln (P1/P0) / (R1/R0-1). Furthermore, we calculated the Modified Cuff-Oscillometric Stiffness Parameter (MCSP) using CSP, age, height and weight. We also measured Cardio-Ankle Vascular Stiffness Index (CAVI), the carotid Intima-Media Thickness (IMT), blood chemistry, and Framingham Risk Score (FRS) for coronary heart disease.

Results

CSP was significantly correlated with CAVI(r= 0.608, p <0.0001). There were significant correlated with IMT, FRS. MCSP was closely correlated with CAVI(r= 0.803, p <0.0001). In addition, CSP, MCSP, and CAVI were associated with blood components as markers of diabetes.

Conclusions

These results suggest that our new method is useful for the screening arteriosclerosis-related disease, and helpful for health care management in home because of easy to use, low cost, and short time measuring.

Keywords: Blood pressure; Arterial stiffness; Cuff-oscillometric method; Cardio-ankle vascular stiffness index

Introduction

The International Diabetes Federation consensus worldwide definition of the Metabolic Syndrome (MS) is central obesity and any two of the diabetes, hypertension or dyslipidemia [1]. In recent years, by rapid aging and change of a lifestyle, prevalence of MS is thought about 20 million people in Japan, so the importance of the health care administration has been proposed. MS is associated with arteriosclerosis, which may increase the risk of cardiovascular morbidity and mortality [2]. Therefore, arterial stiffness measurement is one of the most effective strategies to prevent cardiovascular disease. The Cardio-Ankle Vascular Stiffness Index (CAVI) that is unaffected by blood pressure is used for tests of the degree of arteriosclerosis [3,4]. Carotid Femoral Artery Pulse Wave Velocity (cfPWV) and Augmentation Index (AI), carotid Intima-Media Thickness (IMT) by ultrasonography are also known as other tests to diagnose of arteriosclerosis, however, these methods have difficult operation, it is the inspectionconducted by the specialist in a hospital or clinic, also it is not suitable for daily health care in home [5,6]. Recently, an automatic blood pressure device based on cuff-oscillometric method is widely used for home healthcare. The oscillometric blood pressure device detects sequence of small oscillations in cuff pressure while the pressure is reduced or increased at a constant speed, and determines systolic and diastolic blood pressure by using the specific algorithm for the envelope of these oscillations [7]. Although the device has characteristics of simple operation and short time for blood pressure measurement, it is more useful for prevention of cardiovascular disease to measure arterial stiffness as well. Thus we developed a new arterial stiffness parameter using the change pattern of oscillations as cuff is inflated for measuring blood pressure, and evaluated usefulness of the index as a marker of cardiovascular disease.

Methods

Subjects

Between September 2010 and March 2012, 97 patients who visited Toyama Teishin Hospital undergoing treatment for hypertension (mean age, 67.1 ± 11.5 years old; range, 28-91 years) consisted of 43 males (65.5 ± 12.3 years old) and 54 females (68.4 ± 10.7 years old) were included in this study. The informed consent was obtained from all of

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the enrolled patients. 91 patients were taking anti-hypertensive drugs, 55 patients were taking lipid lowing drug, and 12 patients were taking hypoglycemic agents. 21 patients were current of former smokers.

CAVI measurement

We measured CAVI using a Vasera VS-1000 (Fukuda Denshi Co. Ltd., Tokyo, Japan) as reported previously.3, 4In brief, and cuffs were applied to bilateral upper arms and ankles, with the subject lying supine. Electrocardiographic electrodes were attached to upper arm. A microphone was placed on the sternum for phonocardiography. To detect the brachial and ankle pulse waves with cuffs, a low cuff pressure 30 to 50 mmHg was used. CAVI is vascular stiffness indicator based on the stiffness parameter β theory8 by applying the Bramwell-Hill's equation, and the formula was as follows:

CAVI= a(2 ρ ·ln Ps/Pd· haPWV2 / ΔP)+b

where ρ is blood density, Ps and Pd are respectively the systolic and diastolic pressure, haPWV is pulse wave velocity from the heart to the ankle, ΔP is pulse pressure, a and b are constants to match aortic PWV. The haPWV is obtained by dividing vascular length by the time taken for the pulse wave to propagate from the aortic valve to the ankle. CAVI ≥ 9 is diagnosed as those of arteriosclerosis with doubt.

Theory of new arterial stiffness index

Blood vessel consists of intima, media and adventitia. In lower pressure range, the dispensability of blood vessel is mainly contributed by the media which has rich elastic fibers, but as following intraluminal pressure is higher, mechanical properties are also contributed by the adventitia which has poor elasticity. Therefore, the pressure-diameter relations of blood vessels are nonlinear. To overcome the problem, Hayashi et al. [8] has proposed the following equation to describe pressure-diameter relations of arterial walls in the physiological range:

ln (Pi/Ps)=β(Do/Ds-1)

Where Pi and Do are the intraluminal pressure and the external diameter at each pressure, Ps the standard pressure, and Ds the wall diameter at pressure Ps. That is, since the relationship arterial diameter ratio (Do/Ds) with internal pressure ratio (Pi/Ps) is approximated by an exponential function in the physiological internal pressure range. The coefficient β, called the stiffness parameter represents the structural stiffness of vascular wall. β is known as an index not affected by blood pressure.

On the other hand, several research studies of the pressure-volume relationship with transmural pressures (difference of internal and external pressure) for normal or sclerotic arteries have reported [9-11]. Mackay et al. [9] has reported the change from negative to positive transmural pressure causes an abrupt change in the arterial volume of the normal artery, but the change of the sclerotic artery is less by using isolated normal and sclerotic human arteries. Foster et al. [10] and Babbs et al. [11] have reported pressure-volume relationship for an artery during cuff-oscillometric measurement could describe exponential functions. Furthermore, change of volume in sclerotic artery is less than in normal artery at near zero-transmural pressure [10].

While the cuff is attached to the upper arm and inflated at constant rate, the pulsation of a blood vessel is transmitted in cuff; small oscillations are superimposed on the cuff pressure (Figure 1). The amplitude of the oscillation is analogue to the volumetric change of a blood vessel, and the pattern of the amplitudes are represented the pressure-volume relationship of a blood vessel.Consequently, we added accumulatively the amplitudes of oscillation at each cuff pressure, obtained the characteristic curve of artery similar to pressure-volume relationship. In order to decrease the influence of strength of pulsation, each accumulation value was normalized by total value of accumulation (Figure 2). It assumed that the characteristic curve could approximate by an exponential function in the physiological internal pressure range, we proposed the Cuff-Oscillometric Stiffness Parameter (CSP) as follows:

CSP=ln (P1/P0)/ (R1/R0-1)

Where P0 and P1 are cuff pressure at the ratio of accumulation addition of R0 and R1, respectively. In this research, we give values for R0 and R1 of 30% and 70%, respectively.

Furthermore, using CAVI as a reference, we constructed an algorithm to calculate the modified cuff-oscillometric stiffness parameter (MCSP) using CSP, age, height and weight as follows:

MCSP=a×CSP+b× age+ c× height+ d× weight+ e

Where a to e are constants to match CAVI.

Blood pressure was measured using an automatic electronic blood pressure monitor EW-BU75 (Panasonic Corporation, Osaka, Japan). Cuff is attached to the upper arm, and inflated at rate of 5 mmHg/s until blood pressure measurement is completed. Cuff oscillations were extracted for analysis of arterial stiffness by computer. SBP < 140

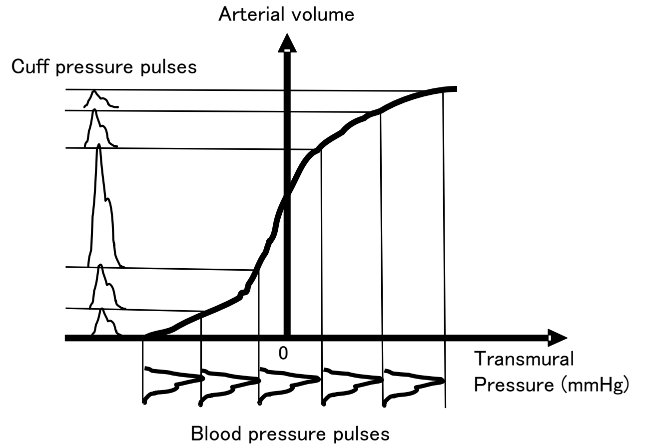

Figure 1: Pressure-volume relationship for an artery including transmural pressures and cutoff pressure pulses during cuff inflation

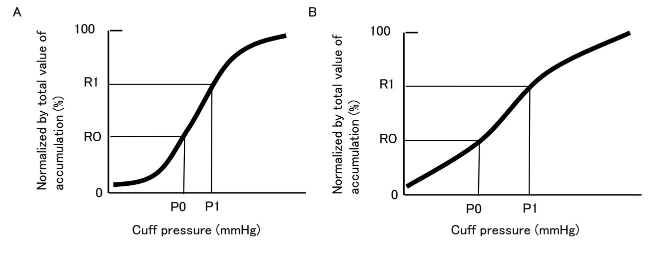

Figure 2: Characteristic curves between cuff pressure and normalized by total value of accumulatively added the amplitudes of oscillation at each cuff pressure.
A. Normal artery
B. Stiff artery

mmHg and DBP < 90 mmHg were defined as the normal range.

IMT measurement

A series of ultrasonographyscanning of carotid artery were performed using Prosound SSD-α10 ultrasound equipment (Hitachi Aloka Medical, Ltd., Tokyo, Japan) with an electrical linear 7.5 MHz transducer. The resolution limit was approximately 0.1 mm. IMT was measured as reported previously [12]. A region of approximately 1.5 cm proximal to the flow divider in the common carotid artery was identified, and far-wall IMT was defined as the distance between the leading edge of the lumen-intima echo and the leading edge of the media-adventitia echo. When an optimal image was obtained, it was frozen in the end-diastolic phase to minimize variability during the cardiac cycle. Three determinations of IMT were made at site of greatest thickness (max IMT) and 1 cm upstream and 1cm downstream from the site of greatest thickness. These three averaged IMT was used as mean IMT. The IMT ≥ 1.1 mm was defined as abnormally high value.

Measurement of blood chemistry

Blood samples were collected after measurement of blood pressure, CAVI, and IMT. The serum concentrations of Total Cholesterol (TC), Low-Density Lipoprotein-Cholesterol (LDL-C), High-Density-Cholesterol (HDL-C), glycosylated hemoglobin (HbA1C), Fasting Blood Sugar (FBS), serum Creatinine (Cr) were measured by standard laboratory procedures. Furthermore, Estimated Glomerular Filtration Rate (eGFR) was calculated by the following equation of the Japanese Society of Nephrology

male:

eGFR (ml/min/1.73m^2) = 194 × Cr-1.094 × age-0.287

female:

eGFR (ml/min/1.73m^2) = 194 × Cr-1.094 × age-0.287 × 0.739

TC (< 220 mg/dl), LDL-C (< 140 mg/dl), HDL-C(< 40 mg/dl), HbA1C(< 6.5%), FBS (< 110 mg/dl), Cr (< 1.0 in male, < 0.7 in female) ,eGFR (< 60 ml/min/1.73 m2) were defined as the normal range, respectively.

Estimation of risk of a future Coronary Heart Disease (CHD) using Framingham risk score

In order to investigate relationship between arterial stiffness and coronary heart disease risk, we calculated the Framingham Coronary Heart Disease (CHD) prediction score [13]. The score can assess the risk of CHD within 10 years for individuals 30 to 74 years old without a history of cardiovascular disease. Gender-specific point for age, blood pressure, HDL-C, LDL-C, diabetes (Y/N), and smoking (Y/N) were added, and the total points were exchanged provability derived from the experience of the Framingham Heart Study.

Statistical analysis

Statistical analysis was performed with SPSS 19 for Windows. Data are expressed as the mean ± 1 Standard Deviation (SD). Comparison of gender was performed using Student's t-test. The constants of a formula for MCSP were determined by using multiple regression analysis. The relationships between CAVI, CSP and MCSP, and between these stiffness indices and various clinical parameters were analyzed using simple regression analysis and Pearson‘s correlation coefficient. Bland-Altman analysis was used to assess the equivalency of CAVI and MCSP. Sensitivity and specificity with respect to diabetes were analyzed using a conventional Receiver-Operating-Characteristic (ROC) curve. Statistical significance was defined at P < 0.05 for all data.

Results

Characteristics of patients

The clinical characteristics of patients are summarized in Table 1. Obesity was defined as BMI ≥ 25 kg/m^2. There were no significant differences in age, BMI, SBP, DBP, PP and HR between male and female. Although the means of BMI, SBP and DBP were within normal range, the mean of max IMT was out of the normal criteria. Moreover, the max IMT was significantly higher in male than in female (1.6 ± 1.2 mm and 1.1 ± 0.3 mm, respectively; p < 0.01). The means of TC, LDL-C and HDL-C were within normal range, but HDL-C was significantly lower in male than in female. Male had a higher FBS than female (141.1 ± 58.4 mg/dl versus 114.5 ± 35.0 mg/dl, respectively; p < 0.05) and Cr (0.9 ± 0.2 mg/dl versus 0.8 ± 0.3 mg/dl, respectively; p < 0.05). HbA1C and eGFR were no significantly differences between genders. FRS was higher in male than in female (14.4 ± 9.4% versus 8.1 ± 3.7%, respectively; p < 0.001). CAVI, CSP and MCSP did not differ

Correlation between CSP and clinical parameters

To clarify the correlation between CSP and various clinical parameters, simple regression analyses were performed (Table 2). CSP was significantly correlated with CAVI (Figure 3). Age, SBP, PP, FBS, and HbA1C were also strong positively correlated with CSP (p < 0.0001). The mean IMT, max IMT, Cr, and FRM were significant positive ly correlated with CSP (p < 0.05). However, Weight, BMI, DBP, LDL-C, TC, and eGFR were significant negatively correlated with CSP (p < 0.05). Height, HR, and HDL-C were not correlated with CSP.

Comparison of MCSP and CAVI

Figure 4 shows the relationship between MCSP and CAVI. The correlation coefficient of all subjects was 0.80 (p < 0.001). Figure 5 shows the results of a Bland-Altman plot of all subjects. The mean difference of two parameters was 0.0, and 92/97 patients (95%) was within 95% limits of agreement (mean ± 1.96SD). The comparison of a correlation analysis result between MCSP, CAVI, and various clinical parameters in Table 3. Age, PP, mean IMT, and FRM were closely correlated with MCSP (p < 0.0001). SBP, max IMT, Cr, FBS, HbA1C were significantly correlated with MCSP (p < 0.05). BMI, DBP, LDL-C, TC, and eGFR were negatively correlated with MCSP (p < 0.005). HR and HDL-C were no significant correlations with MCSP. Age, PP, and FRM were strong positive correlation with CAVI as well as MCSP (p < 0.0001). SBP, mean IMT, max IMT, Cr, FBS, HbA1C were significant positively correlated with CAVI (p < 0.05). BMI, LDL-C, TC, and eGFR were negatively correlated with CAVI (p < 0.005). HR, DBP, and HDL-C were not correlated with CAVI.

Discussion

In the present study, we developed the new method which is measured arterial stiffness simultaneously with blood pressure by oscillometry during cuff inflation. Some parameters have been proposed to assess arterial stiffness using oscillometric blood pressure measurement during cuff deflation. Kaibe et al. [14] are evaluating the Arterial Stiffness Index (ASI) calculated as the oscillometric curve width in each 10 mmHg at 80% of the mean arterial pressure. They reported the correlation coefficient between ASI and brachial-ankle Pulse Wave Velocity (baPWV) was 0.55. Komine et al. [15] developed a method of evaluating whole pressure-volume curve was derived from

	Total (n=97)	Male (n=43)	Female (n=53)	P value
Age (years)	67.1 ± 11.5	65.5 ± 12.3	68.4 ± 10.7	ns
Height (cm)	159.8 ± 10.1	168.0 ± 7.2	153.2 ± 6.7	<0.0001
Weight (Kg)	63.4 ± 12.8	69.7 ± 12.5	58.3 ± 10.7	<0.0001
BMI (Kg/m2)	24.7 ± 3.90	24.6 ± 3.3	24.8 ± 4.3	ns
SBP (mm Hg)	134.9 ± 14.1	134.7 ± 15.2	135.2 ± 13.4	ns
DBP (mm Hg)	83.3 ± 8.4	83.9 ± 9.0	82.9 ± 8.0	ns
PP (mm Hg)	51.6 ± 11.5	50.8 ± 10.8	52.3 ± 12.0	ns
HR (beats/min)	70.0 ± 12.5	67.4 ± 11.4	72.1 ± 13.0	ns
mean IMT (mm)	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.2	ns
max IMT (mm)	1.4 ± 0.8	1.6 ± 1.2	1.1 ± 0.3	<0.01
TC (mg/dl)	191.7 ± 31.2	188.6 ± 31.3	194.0 ± 31.3	ns
LDL-C (mg/dl)	107.3 ± 23.3	106.9 ± 23.1	107.6 ± 23.6	ns
HDL-C (mg/dl)	56.9 ± 15.1	51.7 ± 11.2	60.7 ± 16.5	<0.01
FBS (mg/dl)	126.5 ± 48.6	141.1 ± 58.4	114.5 ± 35.0	<0.05
HbA1c (%)	5.8 ± 0.9	5.8 ± 1.0	5.8 ± 0.8	ns
Cr (mg/dl)	0.8 ± 0.3	0.9 ± 0.2	0.8 ± 0.3	<0.05
eGFR (ml/min per 1.73 m2)	70.2 ± 18.5	69.7 ± 14.8	70.5 ± 21.0	ns
FRM (%)	10.8 ± 7.4	14.4 ± 9.4	8.1 ± 3.7	<0.001
CSP	7.8 ± 2.6	7.9 ± 2.5	7.7 ± 2.7	ns
MCSP	8.8 ± 1.0	8.8 ± 1.1	8.8 ± 0.9	ns
CAVI	8.8 ± 1.2	8.9 ± 1.3	8.7 ± 1.1	ns

Table 1: Characters of patients
Data are presented as the mean ± SD; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; PP, pulse pressure; HR, heart rate; meanIMT, mean intima media thickness; maxIMT, max intima media thickness; TC, total cholesterol; LDL-C, loe density lipoprotein cholesterol; HDL-C, high density lipoprotein cholesterol; FBS, fast blood sugar; HbA1c, glycosylated hemoglobin; Cr, creatinine; eGFR, estimated glomerular Filtration rate; FRM, Framingham risk; CSP, cuff-oscillometric stiffness parameter; MCSP, modified cuff-oscillometric stiffness parameter; CAVI, cardio-vascularstiffness index

	r	P value
Age (years)	0.563	<0.0001
Height (cm)	0.175	ns
Weight (Kg)	-0.319	<0.005
BMI (Kg/m2)	-0.297	<0.005
SBP (mm Hg)	0.452	<0.0001
DBP (mm Hg)	-0.226	<0.05
PP (mm Hg)	0.721	<0.0001
HR (beats/min)	0.001	ns
mean IMT (mm)	0.288	<0.01
max IMT (mm)	0.309	<0.005
TC (mg/dl)	-0.294	<0.01
LDL-C (mg/dl)	-0.286	<0.01
HDL-C (mg/dl)	0.028	ns
FBS (mg/dl)	0.473	<0.0001
HbA1c (%)	0.469	<0.0001
Cr (mg/dl)	0.249	<0.05
eGFR (ml/min per 1.73 m2)	-0.355	<0.001
FRM (%)	0.410	<0.001
CAVI	0.608	<0.0001

Table 2: Coefficients of correlation between CSP and other clinical parameters
BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; PP, pulse pressure; HR, heart rate; meanIMT, mean intima media thickness; maxIMT, max intima media thickness; TC, total cholesterol; LDL-C, loe density lipoprotein cholesterol; HDL-C, high density lipoprotein cholesterol; FBS, fast blood sugar; HbA1c, glycosylated hemoglobin; Cr, creatinine; eGFR, estimated glomerular Filtration rate; FRM, Framingham risk; CAVI, cardio-vascularstiffness index

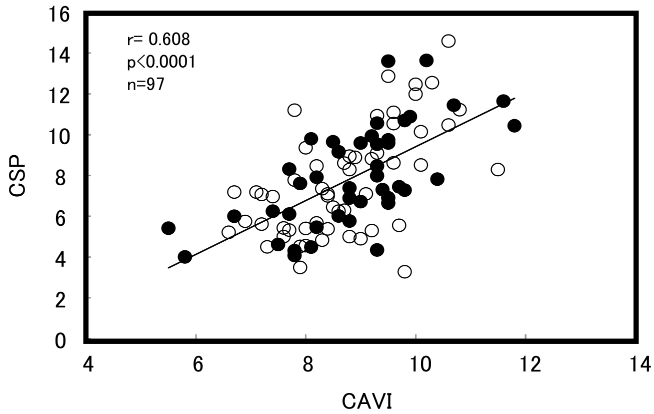

Figure 3: Relationship between CSP and CAVI. Black dots represent male and white dots represent female.

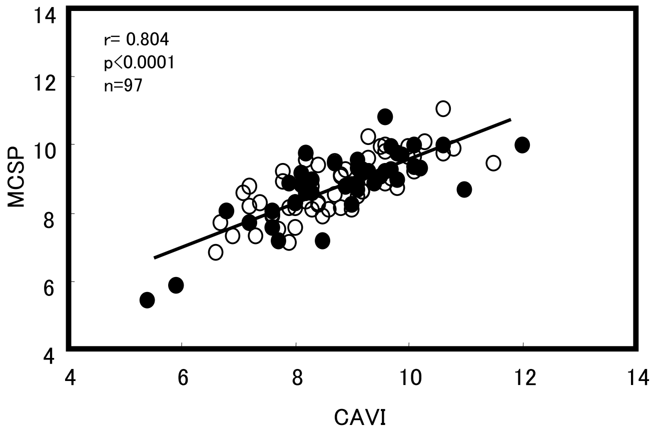

Figure 4: Relationship between MCSP and CAVI. Black dots represent male and white dots represent female.

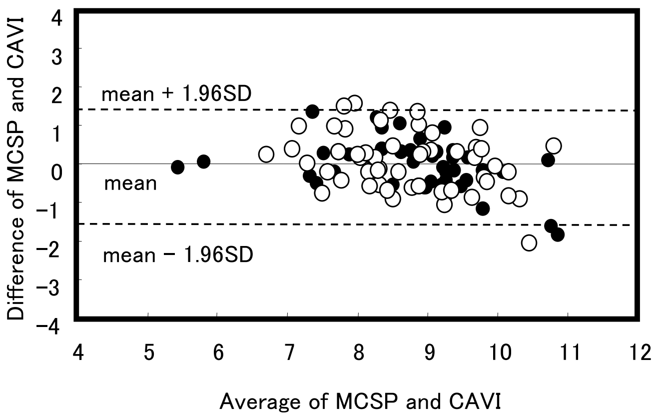

Figure 5: Bland-Altman plot of MSCP and CAVI. Black dots represent male.

numerical integration of the local slopes, and the curve was fitted using an equation and identified a numerical coefficient of the equation as an index of arterial stiffness (API). They reported the correlation coefficient between API and baPWV was 0.53. However, both parameters have assessed with baPWV which was strongly correlated with blood pressure [3]. On the other hand, we have assessed CSP with CAVI which was correlated weakly with blood pressure, compared

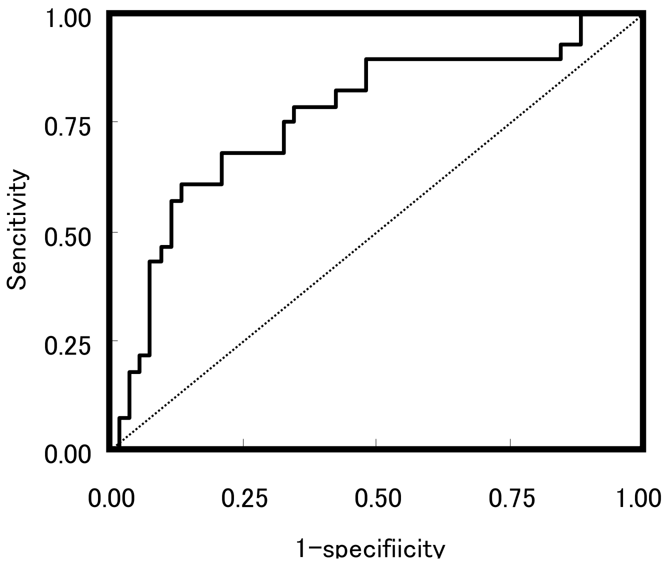

Figure 6: Receiver-operating characteristics (ROC) curves of the ability of CSP to predict diabetes.

with baPWV. CSP is the arterial stiffness parameter based on both arterial pressure-volume relationship and stiffness parameter β which is not affected by blood pressure. β is the slope of the line plotting as the logarithm of internal pressure ratio versus vascular distension ratio. Internal pressure and vascular distension can be approximately exchanged for cuff pressure and amplitude of oscillation, respectively. Therefore, CSP is theoretically independent of blood pressure as well as β or CAVI.

CAVI is the index which reflects aortic stiffness, while CSP is measured at the brachial artery. Nevertheless, CSP is significantly correlated with CAVI ($r = 0.608$), and MCSP by using multiple regression analysis is closely correlated with CAVI ($r = 0.804$). Bland-Altman plots also showed that between MCSP and CAVI is a good agreement. These results indicated that CSP and MCSP are conventional parameters for arterial stiffness. It might be mechanical properties of aorta are associated with those of brachial artery to some extent CSP, MCSP and CAVI were also significantly correlated with mean IMT and max IMT. Okura et al. [16] reported there was a significant positive correlation between CAVI and IMT in patients with essential hypertension ($r = 0.360$), which is similar to our results. These results indicate CSP and MCSP are useful parameter as a marker of arteriosclerotic disease as well as CAVI.

In addition, CSP, MCSP, and CAVI were associated with FBS, HbA1C as a marker of diabetes. Figure 6 shows the ROC curve analysis of the ability of CSP to predict diabetes. Diabetes is defined as HbA1C of ≥ 6.5%, FBS of ≥ 126 mg/dl, or previous diagnosed or use of an oral hypoglycemic. The area under the ROC curve (AUC) for CSP is 0.762. With cut off value of 8.93 for CSP, the ROC curve showed the highest diagnostic accuracy with 86.5% of sensitivity and 60.7% of specificity for discriminating patients with diabetes. The Area under the ROC Curve (AUC) for MCSP and CAVI is 0.716, 0.713, respectively. Figure 7 shows the comparison of ROC curve analysis of the ability of MCSP, and CAVI to predict diabetes. There is no significant difference between the AUCs of the two parameters. The results obtained from this study indicate that our new parameters can be used as screening of diabetes.

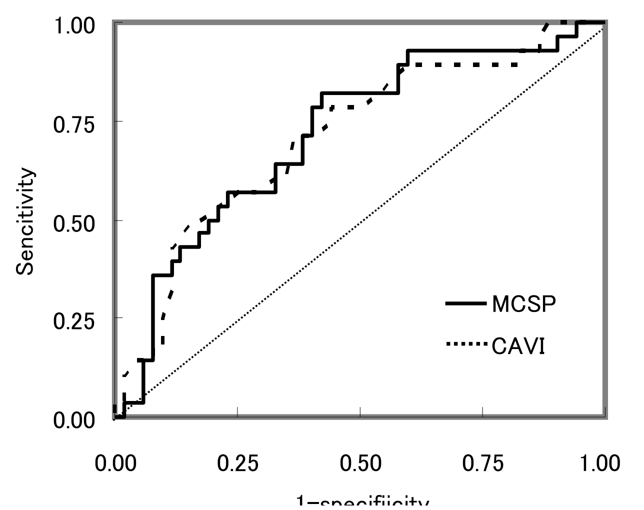

Figure 7: Receiver-operating characteristics (ROC) curves of the ability of MCSP (solid line) and CAVI (dotted line) to predict diabetes.

	MCSP		CAVI	
	r	P value	r	P value
Age (years)	0.0908	<0.0001	0.730	<0.0001
Height (cm)	-0.272	<0.01	-0.219	<0.05
Weight (kg)	-0.577	<0.0001	-0.464	<0.0001
BMI (kg/m2)	-0.510	<0.0001	-0.407	<0.0001
SBP (mm Hg)	0.322	<0.005	0.307	<0.005
DBP (mm Hg)	-0.296	<0.005	-0.172	Ns
PP(mm Hg)	0.612	<0.0001	0.503	<0.0001
HR (beats/min)	-0.159	Ns	0.019	Ns
Mean IMT (mm)	0.440	<0.0001	0.290	<0.01
Max IMT (mm)	0.303	<0.01	0.256	<0.05
TC (mg/dl)	-0.443	<0.001	-0.351	<0.001
LDL-C (mg/dl)	-0.375	<0.001	-0.295	<0.005
HDL-C (mg/dl)	0.033	Ns	0.083	Ns
FBS (mg/dl)	0.332	<0.005	0.363	<0.001
HbA1c (%)	0.307	<0.005	0.305	<0.005
Cr (mg/dl)	0.331	<0.005	0.308	<0.005
eGFR (ml/min per 1.73 m2)	-0.517	<0.0001	-0.438	<0.0001
FRM (%)	0.471	<0.0001	0.435	<0.0005
CAVI	0.804	<0.0001	-	-

Abbreviations: See table 1

Table 3: Coefficients of correlation between MCSP, CAVI, and other clinical parameters

On the other hand, CSP, MCSP, and CAVI were negative correlated with BMI, TC, and LDL-C in the present study. Previous studies on body composition and arterial stiffness have not shown consistent results. In some studies obesity were associated with higher arterial stiffness while other studies found the opposite [17-21]. In the process of arteriosclerosis, it is most likely biochemical changes differ from morphological or biomechanical changes. In the initial stage of arteriosclerosis in hypercholesterolemia, fatty streak is observed. At this stage, cholesterol transferred into tissue following on an endothelial damage may temporarily make arterial wall softer. At the advanced stage of arteriosclerosis, calcification is accompanied with largely increased wall stiffness. Further studies are needed to confirm the relationship between obesity or serum cholesterol and arterial stiffness in the process of arteriosclerosis.

Our results showed CSP, MCSP, and CAVI were significantly correlated with eGFR (-0.36,-0.54,-0.44, respectively). Nakamura et al. [22] has reported the correlation coefficient between CAVI and eGFR was -0.315, this result was very similar to our result. They reported CAVI is closely associated with cystain C levels, suggesting a significant role of arterial stiffness in renal insufficiency. Furthermore CSP, MCSP and CAVI were significantly correlated with FRS (0.41, 0.47, and 0.44, respectively). From these results, CSP or MCSP may be useful for evaluating renal function and CHD risk. Besides arteriosclerosis or cardiovascular disease, arterial stiffness changes with various factors. Shimizu [23] showed that CAVI was significantly elevated immediately after earthquake, and had fallen again six months later. This result indicates psychological stress affects the arterial stiffness.

Noike et al. [24] showed that CAVI value was high in smokers, and ceasing smoking decreased CAVI in a few months. Kurosu et al. [4] reported CAVI value of diabetes was the highest in the early morning, but the value was decreasing in the afternoon in spite of no changes of blood pressure and heart rate, while the value of healthy subjects was stable in all day long. Soska et al. [25] showed that patients underwent 12 weeks of supervised exercise training improved CAVI. From these reports, we can say the measurement of arterial stiffness is important to control lifestyle in daily, and to maintain the health. Consequently, our developed method for measurement of arterial stiffness would be suitable because of easy to use, low cost, and short time measuring. Moreover, measurement during cuff inflation is not so much influence of arterial spasm.

In conclusion, we have investigated the new method which is measured arterial stiffness simultaneously with blood pressure by using cuff-oscillometric blood pressure device during cuff inflation. We developed the new arterial stiffness parameter CSP based on both arterial pressure-volume relationship and stiffness parameter β theory, and constructed MCSP using CSP, age, weight and height so as to match CAVI. These arterial stiffness parameters significantly correlated with CAVI. In addition, the parameters associated with some markers of diabetes, cardiovascular, or kidney disease as well as CAVI. Accordingly, the arterial stiffness parameters are useful for the screening arteriosclerosis-related disease and helpful for health care management in home.

Study Limitations

The present study has some limitations. A small number of patients with hypertension were enrolled and analyzed using cuff oscillometric pulses in this study. The oscillometric pulses may be affected by various factors such as the elastic property of cuff and interference between tissues of upper arm and cuff. The irregular shape of pulse such as arterial fibrillation or other arrythmias may also influence the values of CSP. We also could not evaluate the relationship CSP and heart rate, arterial wall viscosity, blood flow. Further studies should be needed to clarify in detail the degree of the effects by these factors.

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