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

Kazuhiro Ide1,*, Tomoya Kusakabe1, Atsuhiro Shimakura2 and Masanobu Takata2

1 Home Appliances Development Center, Corporate Engineering Division, Appliances Company, Panasonic Corporation, Shiga, Japan
2 Toyama Teishin Hospital, Toyama, Japan

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 the participants.

*Corresponding author: Kazuhiro Ide, Home Appliances Development Center, Corporate Engineering Division, Appliances Company, Panasonic Corporation, Shiga, Japan, Tel: +8177-567-9965; E-mail: ide.kazuhiro.jp.panasonic.com

Received January 9, 2014; Accepted February 12, 2014; Published February 19, 2014

Citation: Ide K, Kusakabe T, Shimakura A, Takata M (2014) Non-Invasive Measurement of Arterial Stiffness Using the Analysis of Oscillometric Waveform during Cuff-Inflation. Angiol 2: 123. doi: 10.4172/2329-9495.1000123

Copyright: © 2014 Ide K, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.
the enrolled patients. 91 patients were taking anti-hypertensive drugs, 55 patients were taking lipid lowering 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, 4 In 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 \( \beta \) theory by applying the Bramwell-Hill’s equation, and the formula was as follows:

\[
\text{CAVI} = a(2 \ln \frac{P_s}{P_d} \cdot \text{haPWV}/\Delta P)+b
\]

where \( \rho \) is blood density, \( P_s \) and \( P_d \) are respectively the systolic and diastolic pressure, haPWV is pulse wave velocity from the heart to the ankle, \( \Delta P \) 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:

\[
\ln \frac{P_i}{P_s} = \beta \left( \frac{D_o}{D_s} - 1 \right)
\]

Where \( P_i \) and \( D_o \) are the intraluminal pressure and the external diameter at each pressure, \( P_s \) the standard pressure, and \( D_s \) the wall diameter at pressure \( P_s \). That is, since the relationship arterial diameter ratio \( (D_o/D_s) \) with internal pressure ratio \( (P_i/P_s) \) is approximated by an exponential function in the physiological internal pressure range. The coefficient \( \beta \), called the stiffness parameter represents the structural stiffness of vascular wall. \( \beta \) 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:

\[
\text{CSP} = \ln \left( \frac{P_1}{P_0} \right) / (R_1/R_0-1)
\]

Where \( P_0 \) and \( P_1 \) are cuff pressure at the ratio of accumulation addition of \( R_0 \) and \( R_1 \), respectively. In this research, we give values for \( R_0 \) and \( R_1 \) 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:

\[
\text{MCSP} = a\times\text{CSP} + bx + c\times\text{height} + dx\times\text{weight} + e
\]

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
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 1 cm 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

\[
\text{eGFR (ml/min/1.73m^2)} = 194 \times \text{Cr}^{-1.094} \times \text{age}^{-0.287}
\]

\[
\text{eGFR (ml/min/1.73m^2)} = 194 \times \text{Cr}^{-1.094} \times \text{age}^{-0.287} \times 0.739
\]

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/m². 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 significantly.

**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 the mean IMT, max IMT, and Cr, and FRM were significant positively correlated with MCSP (p < 0.0001). The mean IMT, max IMT, Cr, and FRM were significant positively correlated with CAVI (p < 0.05). However, Weight, BMI, DBP, LDL-C, TC, and eGFR were significant negatively correlated with CAVI (p < 0.05). Height, HR, and HDL-C were not correlated with CAVI.

**Comparison 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 strongly positively correlated with CSP (p < 0.0001). The mean IMT, max IMT, Cr, and FRM were significant positively correlated with CSP (p < 0.05). However, Weight, BMI, DBP, LDL-C, TC, and eGFR were significantly negatively correlated with CSP (p < 0.05). Height, HR, and HDL-C were not correlated with CSP.

**Discussion**

In the present study, we developed the new method which is measured arterial stiffness simultaneously with blood pressure by oscillimetry during cuff inflation. Some parameters have been proposed to assess arterial stiffness using oscillimetric blood pressure measurement during cuff deflation. Kaibe et al. [14] are evaluating the Arterial Stiffness Index (ASI) calculated as the oscillimetric 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...
Table 1: Characters of patients

| Character          | 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 2: Coefficients of correlation between CSP and other clinical parameters

| Character          | 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, low 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-vascular stiffness index.
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 with baPWV. CSP is the arterial stiffness parameter based on both arterial pressure-volume relationship and stiffness parameter $\beta$ which is not affected by blood pressure. $\beta$ 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 $\beta$ 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 $\geq 6.5\%$, FBS of $\geq 126$ 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.
At this stage, cholesterol transferred into tissue following on an process of arteriosclerosis, it is most likely biochemical changes differ among 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 arrhythmias 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.

**References**

1. Saely CH, Koch L, Schmid F, Marte T, Aczel S, et al. (2006) Adult Treatment Panel III 2001 but not International Diabetes Federation 2005 criteria of the metabolic syndrome predict clinical cardiovascular events in subjects who underwent coronary angiography. Diabetes Care 29: 901-907.

---

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

| Parameter | 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 | 0.306 | <0.005 |
| 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 |
| FRS (%) | 0.471 | <0.0001 | 0.435 | <0.0005 |
| CAVI | 0.804 | <0.0001 | - | - |

Abbreviations: See table 1

---

**Citation:** Ide K, Kusakabe T, Shimakura A, Takata M (2014) Non-Invasive Measurement of Arterial Stiffness Using the Analysis of Oscillometric Waveform during Cuff-Inflation. Angiol 2: 123. doi: 10.4172/2329-9495.1000123
2. Andreadis EA, Tsourous Gi, Tzavara CK, Georgiopoulos DX, Katsanou PM, et al. (2007) Metabolic syndrome and incident cardiovascular morbidity and mortality in a Mediterranean hypertensive population. Am J Hypertens 20: 558-564.

3. Shirai K, Utino J, Otsuka K, Takata M (2006) A novel blood pressure-independent arterial wall stiffness parameter; cardio-ankle vascular index (CAVI). J AtherosclerThromb 13: 101-107.

4. Shirai K, Hiruta N, Song M, Kurosu T, Suzuki J, et al. (2011) Cardio-ankle vascular index (CAVI) as a novel indicator of arterial stiffness: theory, evidence and perspectives. J AtherosclerThromb 18: 924-938.

5. Laurent S, Cockcroft J, Van Bortel L, Boutouyrie P, Giannattasio C, et al. (2006) Non-invasive assessment of arterial stiffness using oscillometric blood pressure measurement. Biomed Eng Online 11: 6.

6. Okura T, Watanabe S, Kurata M, Manabe S, Koreshawa M, et al. (2007) Relationship between cardio-ankle vascular index (CAVI) and carotid atherosclerosis in patients with essential hypertension. Hypertens Res 30: 335-340.

7. Daniels PG, Tritos NA, M Stuber, RM Botnar, KV Kissinger, et al. (2003) Comparison of aortic elasticity determined by cardiovascular magnetic resonance imaging in obese versus lean adults. Am J Cardiol 91: 195-199.

8. Resnick LM, Milliman D, Cunnings AJ, Pipe JG, Evelhoch JL, et al. (1997) Direct magnetic resonance determination of aortic distensibility in essential hypertension: relation to age, abdominal visceral fat, and in situ intracellular free magnesium. Hypertension 30: 654-659.

9. Wildman RP, Mackay RH, Bostom A, Thompson T, Sutton-Tyrrell K (2003) Measures of obesity are associated with vascular stiffness in young and older adults. Hypertension 42: 468-473.

10. Chambless LE, Folsom AR, Clegg LX, Sharrett AR, Shahar E, et al. (2000) Association between cardio-ankle vascular index (CAVI) and carotid intima-media thickness and large artery stiffness at the age of 36 years. J Hypertens 22: 145-155.

11. Leeson CP, Whincup PH, Cook DG, Mullen MJ, Donald AE, et al. (2000) Cholesterol and arterial distensibility in the first decade of life: a population-based study. Circulation 101: 1533-1538.

12. Nakamura K, Iizuka T, Takahashi M, Shimizu K (2012) An increase in CAVI and its meaning due to the Great East Japan Earthquake. CAVI Now & Future 1: 51-55.

13. Nakamura K, Tomaru T, Yamamura S, Miyashita Y, Shirai K, et al. (2008) Cardio-ankle vascular index is a candidate predictor of coronary atherosclerosis. Circ J 72: 598-604.

14. Kalso M, Chishi M, Komai N, Ito N, Katsuya T, et al. (2002) Arterial stiffness index: a new evaluation for arterial stiffness in elderly patients with essential hypertension. Geria and GerontinIZ 199-205.

15. Komine H, Asai Y, Yokoi T, Yoshizawa M (2012) Non-invasive assessment of arterial stiffness using oscillometric blood pressure measurement. Biomed Eng Online 13: 175-184.

16. Andreadis EA, Tsourous Gi, Tzavara CK, Georgiopoulos DX, Katsanou PM, et al. (2007) Metabolic syndrome and incident cardiovascular morbidity and mortality in a Mediterranean hypertensive population. Am J Hypertens 20: 558-564.

Submit your next manuscript and get advantages of OMICS Group submissions

Citation: Ide K, Kusakabe T, Shimakura A, Takata M (2014) Non-Invasive Measurement of Arterial Stiffness Using the Analysis of Oscillometric Waveform during Cuff-Inflation. Angiol 2: 123. doi: 10.4172/2329-9495.1000123

Unique features:
• User friendly/feasible website-translation of your paper to 50 world's leading languages
• Audio Version of published paper
• Digital articles to share and explore

Special features:
• 300 Open Access Journals
• 25,000 editorial team
• 21 days rapid review process
• Quality and quick editorial, review and publication processing
• Indexing at PubMed (partial), Scopus, EBSO, Index Copernicus and Google Scholar etc
• Sharing Option: Social Networking Enabled
• Authors, Reviewers and Editors rewarded with online Scientific Credits
• Better discount for your subsequent articles

Submit your manuscript at: http://www.omicsonline.org/submission/