

Arterial Stiffness and Blood Pressure Self-Measurement With Loaned Equipment

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Background: A cross-sectional study was carried out in 415 hypertensive and normotensive subjects to determine the correlation between loaned self-measurement blood pressure (LSEM), arterial stiffness, and the different factors that contribute to it.

Methods: The LSEM model consists of lending a number of sphygmomanometers, property of the clinic, to patients for 3-day periods. Arterial stiffness was evaluated using the carotid-to-femoral pulse wave velocity (PWV), using an automatic apparatus. To determine the importance of each of these factors, a multiple linear regression analysis was carried out.

Results: Of the total number of patients, 78% were women, the average age was 57 ± 12 years, 55.8% were hypertensive, and 38.8% were diabetic. The PWV average

for the whole group was 12.1 ± 4.2 m/sec. The correlation coefficients between the PWV and the self-measurements were 0.49 ($P < .001$) for the pulse pressure, and 0.46 ($P < .001$) for the systolic blood pressure (BP), respectively. Both represented 13.0 % of the total variation. The diastolic BP obtained by self-measurement and the serum creatinine values also had an effect on the stiffness, with 2.3 % ($P = .05$) each one.

Conclusions: The pulse pressure readings with self-measurement correlate better with the arterial stiffness, compared with the readings taken in the office. Am J Hypertens 2003;16:375-380 © 2003 American Journal of Hypertension, Ltd.

Key Words: Home blood pressure, arterial stiffness, essential hypertension, pulse wave velocity.

New indicators are needed to evaluate cardiovascular risk in patients, particularly those that can be identified easily in the office. Arterial stiffness, determined with the pulse wave velocity (PWV), can be an additional marker to determine the cardiovascular risk in a patient.^{1,2}

Recently, two studies have determined the PWV value as a risk predictor. In the Blacher et al³ study, it was found that PWV values superior to 13 m/sec were associated with an increase in cardiovascular mortality. Laurent and group⁴ demonstrated that in hypertensive subjects, a 5 m/sec increase in arterial stiffness is associated with a 50% increase in cardiovascular mortality.

Blood pressure is one of the principal determinants for arterial stiffness in the subjects.^{2,5} As various studies have reported the possibility that some forms of treatment may have independent effects on blood pressure (BP) and ar-

terial stiffness, reliable BP readings in this type of study become more important.^{6,7}

Blood pressure measurement taken outside the office may be an alternative to solve this problem; 24-h ambulatory BP monitoring has been used. The correlation between the systolic BP and the PWV is 0.70, but the technique is expensive and is difficult to realize.⁸ The loaned self-measurement BP (LSEM) is a technique with acceptable reproducibility, is low cost, can be done from the office, and is easy to teach to patients.⁹

In this article, we present some of the factors that affect arterial stiffness in normotensive and hypertensive subjects, including the correlation between the LSEM and the PWV, used as an index of arterial stiffness.

Methods

The main objective of this cross-sectional study was to determine the correlation between BP self-measurement

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and arterial stiffness. The factors that could influence arterial stiffness in this population were also investigated. Subjects included were more than 15 years of age, of both sexes, and normotensive or hypertensive. Patients who were taking antihypertensive medications were also included in the study, if the medication and dosage had not been changed for at least 2 months.

Patients excluded were those with secondary hypertension, type I diabetes, renal insufficiency (serum creatinine >2.5 mg/dL), cerebral or myocardial infarction, or serious concomitant illnesses.

A case report form was completed for each patient, which included sex, age, weight, height, physical activity, tobacco use, and presence of hypertension, diabetes, and dyslipidemia, as well as current use of medications and any history of cardiovascular complications.

After data collection, repeated BP readings were carried out in the office, and blood samples were taken. Patients were then instructed on BP self-measurement, and the PWV was measured. Participating subjects signed a consent form.

The pulse pressure (PP) was calculated by subtracting the diastolic BP from the systolic BP. The mean BP (MBP) was calculated with: $MBP = \text{Diastolic BP} + PP/3$.

Diabetes mellitus was defined by the use of oral antidiabetic drugs or insulin, or by glycemia >126 mg/DL.¹⁰ Dyslipidemia was defined by total cholesterol ≥ 220 mg/dL, or the use of a hypocholesterolemic drug.¹¹ The total cholesterol/HDL index was calculated.

Tobacco use was considered according to current use, without specifying quantity or duration. A high alcohol consumption was defined as more than two drinks a day. Physical activity was determined with the question: Do you do any type of exercise? Obesity was defined as a body mass index (BMI) ≥ 30 (weight in kilograms divided by height in meters squared).

Evaluation of Other Parameters

After BP self-measurements were completed, fasting venous blood samples were obtained. The plasma was immediately separated for routine blood chemistry with known techniques. Cholesterol and triglycerides were determined by the enzymatic method.¹² In the case of HDL, those with a density less than 1063 were precipitated, and the remainder was analyzed with the enzymatic method.¹³ The cholesterol-HDL calculation was determined in those patients with triglycerides levels <400 mg/dL using the Friedewald equation.¹⁴

The last procedure was to determine PWV with the Complior (Colson, Paris, France).¹⁵ One of the transducers was placed on the common carotid artery, and the other on the femoral artery. A PWV value >13 m/sec was considered a cardiovascular risk value, according to Blacher et al.³

Hypertension was defined as BP $\geq 140/90$ mm Hg, or if the patients were taking antihypertensive treatment. The BP measurements were taken by a trained nurse, with the patient in a sitting position, after at least a 10-min rest, and having restrained from drinking coffee or tea for at least 1 h, or from smoking for at least 15 min. Any type of medication that could temporarily modify BP was prohibited.

A mercury-in-glass sphygmomanometer was used to measure BP on at least two different occasions, three times in succession at 3-min intervals. Diastolic BP was recorded at the disappearance of Kortkoff sounds (phase V).

The oscillometric technique with automatic manometers was used (Omron 713C brand) for the LSEM. These manometers have not been previously validated. A proper size cuff was used on each patient. These devices were calibrated every 25 loans, using an Y-tube connection in one end of a mercury-in-glass sphygmomanometer, and the other end was connected to the automatic equipment. Simultaneous BP readings should not differ by more than ± 5 mm Hg between the two devices.

The LSEM technique has been previously published.⁹ Patients or helpers were instructed on the proper technique for this BP self-measurement. In the case of incomplete readings, patients were reinstructed and a new self-measurement week was programmed. Self-measurements were considered valid if 85% of the readings were completed, including at least one reading during each of the three daily periods.

Statistical Analysis

Data are presented with the average value \pm standard deviation or as percentages in the case of the categorical values. The differences between the distinct age groups were estimated with a one-way ANOVA variance analysis for the numerical variables.

To determine the factors that are independently related to the PWV, a univariate analysis was done, and the Pearson correlation coefficients were calculated and this was presented as a linear regression graph. The correlation significance between PWV and hemodynamic parameters was done with a regression variance analysis. A multivariate analysis was carried out to estimate the association between the risk factors and the hemodynamic values with the arterial stiffness. The following variables were included; age, sex, BMI, BP, MBP, PP, heart rate, lipid levels, total cholesterol/cholesterol-HDL index, tobacco use, physical activity, presence of diabetes, glucose level, presence of proteinuria, and creatinine levels.

To determine whether the BP office readings or the LSEM readings had a greater relation with the PWV and the other cardiovascular risk factors, the regression coefficient was calculated. At the same time the stepwise regression analysis was used to determine which variable was selected first. A value of $P < .05$ was considered significant. The Minitab Inc. 1998 version program

Table 1. Population description ($n = 415$)

Variables	Mean \pm Standard Deviation	Min-Max
Men:women ($n, \%$)	92 (22.2):323 (77.8)	
Age (y)	57 \pm 12	18-88
Weight (kg)	71.8 \pm 14.1	37-126
Height (m)	1.57 \pm 0.12	1.36-1.85
BMI (kg/m ²)	29.0 \pm 5.5	14.3-45.8
Total plasma cholesterol (mg/dL)	210 \pm 37	106-380
HDL plasma cholesterol (mg/dL)	50 \pm 21	26-98
LDL plasma cholesterol (mg/dL)	129 \pm 38	215-296
Triglycerides (mg/dL)	153 \pm 36	63-464
TC/HDL index	4.5 \pm 1.1	2.2-9.5
Plasma creatinine (mg/dL)	0.9 \pm 0.2	0.4-2.5

(Minitab Inc., State College, PA) was used for the calculations.

Results

A total of 415 subjects completed the study out of 426 initial patients. Table 1 shows the characteristics of the study population. Of the total population, 55.8% were hypertensive (85% treated; 18.2% diuretics, 22.3% β -blockers, 36% angiotensin-converting enzyme [ACE] inhibitors, 23.5% combination), 38.8% were diabetic, 32% were dyslipidemic, and 16.4% were smokers.

Table 2 shows the hemodynamic values found in the study population; the average PWV was 12.2 ± 4.2 m/sec.

Table 3 shows the correlation coefficients of the variables studied in the population with the PWV. The variables that showed the largest correlation coefficients were the PP obtained by BP self-measurement, followed by the systolic BP obtained in the same fashion. In the case of the diastolic BP, the correlation coefficients had low values, and were only significant with self-measurement.

Fig. 1 shows the correlations between the PWV and age, and the PP values obtained with self-measurement.

Table 4 shows the hemodynamic data in the different age groups of the study population. The PWV, the office systolic BP, and the office PP showed a progressive elevation with each age group. The office diastolic BP diminished in the more than 60 years old age group. Neither the MBP obtained in the office nor the MBP obtained with self-measurement differed between the age groups.

Table 5 contains the multiple linear regression analysis of the PWV. The factors with the most influence on arterial stiffness were the mean systolic BP taken with self-measurement and age. Both represented 12.96% of the total variation. The mean diastolic BP taken by self-measurement and the serum creatinine levels also had an influence on the stiffness. The glucose level, total cholesterol, cholesterol-HDL, and cholesterol-LDL levels, along with the BMI, antihypertensive medication use and tobacco use, did not reveal any significance in the multiple linear regression model.

Table 2. Characteristics of the studied population ($n = 415$): hemodynamic parameters

Values	Mean Standard Deviation	Min-Max
Systolic BP (mm Hg)	137 \pm 23	86-214
Diastolic BP (mm Hg)	82 \pm 12	58-116
Heart rate (beats/min)	73 \pm 9	52-100
Mean BP (mm Hg)	102.5 \pm 14.0	68.6-142
Pulse pressure (mm Hg)	57.7 \pm 18.0	22-136
Self-systolic BP (mm Hg)	131 \pm 21	93-211
Self-diastolic BP (mm Hg)	78 \pm 12	52-112
Self-heart rate (beats/min)	72 \pm 9	52-108
Self-PP (mm Hg)	52.4 \pm 15.8	27-120
Self-mean BP (mm Hg)	97.4 \pm 13.8	65-143
PWV (m/seg)	12.2 \pm 4.2	4.7-39.7

BP = blood pressure; PWV = pulse wave velocity.

Table 3. Pearson correlation coefficients for the variables studied in the population with the pulse wave velocity

Variable	Correlation Coefficient	Variable	Correlation Coefficient
Age (y)	0.43 (<0.01)	Mean office BP	0.21 (0.01)
Office systolic BP (mm Hg)	0.38 (<0.01)	Mean self-BP	0.40 (<0.01)
Self-systolic BP (mm Hg)	0.46 (<0.01)	Office PP	0.20 (<0.01)
Office diastolic BP (mm Hg)	0.10 (0.14)	Self-PP	0.49 (<0.01)
Self-diastolic BP (mm Hg)	0.17 (0.01)		

Abbreviation as in Table 2.

Discussion

Studying arterial stiffness can lead to a better understanding of the factors that affect the arterial vessels, in normal patients as well as in patients with arterial damage.^{2,8,15}

An adequate reading of the BP is fundamental in this type of study; BP is one of the factors that is closely linked

to arterial stiffness.^{2,16,17} This is of particular importance because recently it has been proposed that certain antihypertensive medications (such as the ACE inhibitors and certain β -blockers) can modify the arterial structure, independently of the effect on BP.^{4,6}

Several studies have determined the correlation between office BP readings and the extent of arterial stiffness. Ngim et al¹⁸ reported a correlation coefficients of 0.57 for systolic BP and 0.53 for diastolic BP in populations of normotensive and hypertensive subjects. Ferreira and group¹⁹ found in 120 male adult subjects values of 0.24 for systolic BP and 0.21 for diastolic BP. These findings differ from that of Asmar et al,¹⁵ in which the correlation coefficients between the systolic BP and PWV values showed an value of 0.05. The differences between these reported studies could be due to the different standardization techniques in conventional measurements, and the distinct study populations.

Other investigators have taken BP readings outside the office, trying to improve the correlation with arterial stiffness. Using 24-h ambulatory BP monitoring, Asmar et al⁸ found a correlation coefficient value of 0.46 between the PWV and the systolic BP in a population of hypertensive subjects. The MBP showed a value of 0.22, and the diastolic BP did not reach statistical significance.

According to our literature search, there are no accounts on the usefulness of BP self-measurement in arterial stiffness studies. Using the LSEM, systolic BP values had higher correlations with the PWV, but the diastolic BP did not reach significant values. Other researchers have also reported the lack of correlation with the diastolic BP.^{8,17,18} The increase in stiffness in the great arteries is a multifactor biological process, in which aging and pathologic processes such as diabetes, kidney damage, and arterial hypertension play a predominant role.^{2,16,20,21}

In our study we observed, as other investigators have mentioned, that the PWV increases with age.^{3,22} In our population the most important hemodynamic factor for the PWV values was the systolic BP taken by self-measurement. In our study, the systolic BP and the office PP increased with age, and diastolic BP in the oldest age group. These changes were not observed with the LSBP. This could be due to some methodologic problem in our

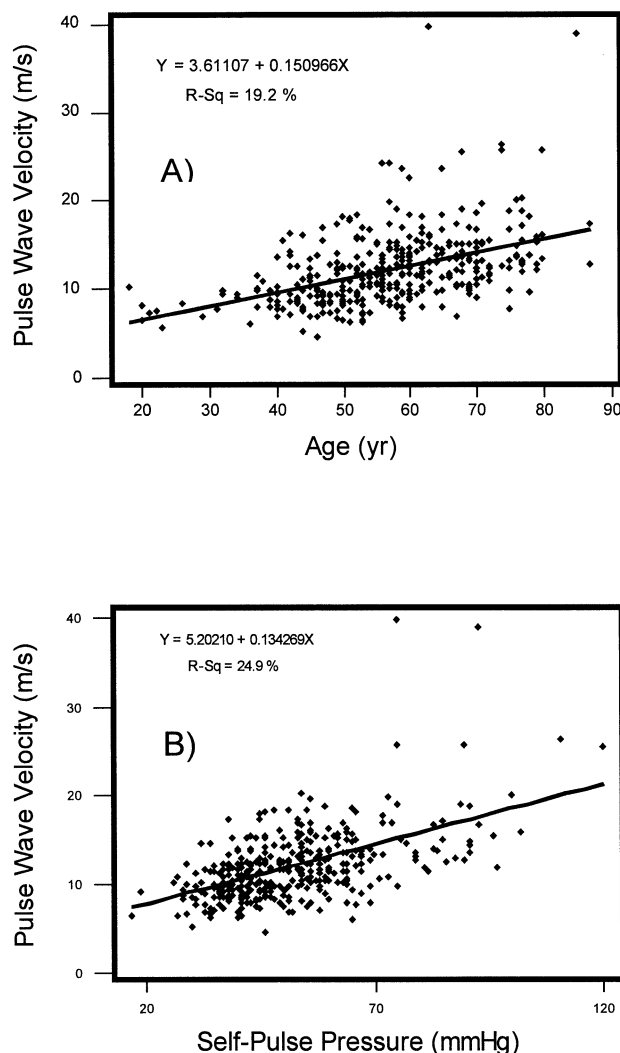


FIG. 1. Correlations between the pulse wave velocity and age (A), and the PP values obtained with self-measurement (B).

Table 4. Hemodynamic parameters in the different age groups (n = 415)

Variable	Group 1 <40 y n = 132	Group 2 40-59 y n = 148	Group 3 >60 y n = 135	Scheff'e Multicomparison Test					
				1	2	1	3	2	3
Office systolic BP (mm Hg)	123.0 ± 19	138.5 ± 27	146.1 ± 21	*		*			*
Self-systolic BP (mm Hg)	124.0 ± 21	129.4 ± 20	140.3 ± 21	NS		*			*
Office diastolic BP (mm Hg)	83.1 ± 13	85.3 ± 12	81.0 ± 10	NS		NS			*
Self-diastolic BP (mm Hg)	80.0 ± 15	80.2 ± 12	78.1 ± 10	NS		NS			NS
Mean office BP (mm Hg)	96.3 ± 15	103.0 ± 15	102.7 ± 12	NS		NS			NS
Mean self-BP (mm Hg)	94.6 ± 17	96.6 ± 14	98.9 ± 13	NS		NS			NS
Office PP	39.5 ± 18	53.1 ± 15	65.1 ± 18	*		*			*
Self-PP	44.1 ± 10	49.1 ± 13	62.1 ± 16	NS		*			*
PWV (m/seg)	8.4 ± 1	11.3 ± 3	14.3 ± 4	*		*			*

NS = not significant; other abbreviations as in Tables 2 and 3.
* P < .01.

study, possibly the use of antihypertensive medications or tobacco use close in time of the BP readings. Another point to consider is the use of automatic manometers that have not been previously validated. This could be an additional factor for error.

In sophisticated studies using direct magnetic resonance, it has been demonstrated that hypertensive individuals suffer from a reduction in arterial distensibility.¹⁶ Other techniques have been used to determine the factors that modify arterial rigidity. Fernandez et al¹⁷ found that age, systolic BP, and hyperglycemia were factors that had the greatest influence on the PWV, in contrast with our population, where glucose levels were not statistically significant.

Asmar et al,²² using the same technique as in our study, reported that in a French population whose cardiovascular risk factors had not been treated, age, gender, systolic BP, and heart rate were the variables significantly associated with arterial stiffness. Other studies have reported that diabetes mellitus and glucose intolerance are factors that modify arterial rigidity.²³

These relations vary according to the type of population studied. In the Asmar et al⁸ study, where a population with atherosclerotic complications was included, age, serum creatinine, cholesterol-HDL levels, and tobacco use were the factors most related to arterial stiffness.

The PP and reduction in the diastolic BP were the hemodynamic parameters that had the closest correlation with the PWV.

Recently, the first longitudinal study demonstrated that an increase in arterial stiffness is associated with an increase in cardiovascular mortality.⁴ In the multivariate analysis, the PWV was significantly related to the presence of previous cardiovascular illness, age, heart rate, and diabetes mellitus. In this model, neither the PP readings nor the MBP taken in the office were related to mortality.

Studies where medications have been used with the objective of modifying arterial stiffness have demonstrated a possible effect on the vessels.^{6,24} Guerin et al²⁴ have described that patients with renal damage, and in whom antihypertensive treatments did not provoke a reduction in the PWV, have a higher cardiovascular mortality when compared to the group where there was a significant reduction in arterial stiffness.

The LSEM can help facilitate the study methodology where arterial stiffness is evaluated. It could define the risk groups, such as patients in the hypertensive range readings in the office, and normotensive outside of that range. Also it would help differentiate the effect on arterial stiffness, the different therapeutic measures used to avoid vascular damage, and reduce cardiovascular mortality.

Table 5. Stepwise linear regression of pulse wave velocity

Variables	Reg. Coeff	SE	Part Adj R ²	Sum. Adj. R ²	P
Self-systolic BP (mm Hg)	0.085	0.030	9.36%	6.76%	<.001
Age (y)	0.117	0.021	8.64%	12.96%	<.001
Self-diastolic BP (mm Hg)	-0.079	0.037	2.34%	14.52%	.05
Creatinine (mg/dL)	1.910	0.967	2.34%	16.04%	.05
Glucose (mg/dL)	0.007	0.004	1.53%	17.06%	.47

Abbreviations as in Tables 2-4.

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