# Arterial Distensibility and Ambulatory Blood Pressure Monitoring in Essential Hypertension

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**Arterial distensibility estimated by carotid femoral pulse wave velocity was evaluated in 22 patients with sustained essential hypertension, together with 3 different methods of blood pressure (BP) measurement: mercury sphygmomanometer, semiautomatic BP recording using the Dinamap apparatus and 24-hour ambulatory BP monitoring using a Spacelabs monitor. Although pulse wave velocity did not correlate with BP measured by mercury sphygmomanometer, it strongly and positively correlated with BP measurements using the other 2 procedures. The best correlation was observed with ambulatory BP with respect to systolic BP only ($r = 0.685$, $p < 0.001$). Since cardiovascular morbidity and mortality in hypertensive patients is mainly related to lesions of the large arteries, the determination of pulse wave velocity together with ambulatory BP measurements is proposed for the evaluation of cardiovascular risk.**

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There is a common consensus that casual and clinic blood pressure (BP) measurements are predictive of subsequent cardiovascular damage.[1] Unfortunately, they can be somewhat unsatisfactory, especially when BP is in the range of so-called mild hypertension.[1] Several studies have shown that ambulatory BP correlates more strongly than clinic or casual BP with echocardiographic indexes of left ventricular hypertrophy[2–4] or with indexes of target organ damage in the heart, optic fundi and kidney.[5–7] However, since the cardiovascular morbidity and mortality of hypertensive patients is mainly related to lesions of the large arteries,[1–8] noninvasive indexes of arterial disease may be more suitable than echocardiographic findings and target organ damage for the evaluation of cardiovascular risk.

Recent studies have shown that, in patients with essential hypertension, not only the resistive vessels are affected but also the large arterial vessels, and the compliance of the latter is significantly reduced.[9,10] In studying the arterial modifications in hypertension, the determination of vascular impedance, which reflects the resistive, capacitive and inertial components of the vessels, is certainly the most accurate index.[11] In particular, characteristic impedance has been used in evaluating arterial distensibility.[11,12] This parameter is directly related to the corresponding pulse wave velocity in the arterial segment under study, and inversely related to the cross-sectional area of the artery. Because the latter factor is only slightly modified by BP,[13] pulse wave velocity alone is widely used as an index of arterial compliance and distensibility.[10,11] Indeed, regional pulse wave velocity can easily be determined from the time delay between pulse waves recorded simultaneously at proximal and distal sites, related to the distance between these sites. In the present study, pulse wave velocity, used as an index of arterial distensibility, was measured in hypertensive patients and related to the level of BP determined by 3 different procedures: mercury sphygmomanometer, semiautomatic BP monitoring using a Dinamap apparatus (model 1846-P) and ambulatory BP measurement using the Spacelabs monitor (model 5200).

## Methods

**Patients:** The study was caried out in 22 men ages 22 to 61 years. Mean age was 47 ± 9 years (± 1 standard deviation). Mean weight was 76 ± 9 kg and mean

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height was 173 ± 8 cm. In all subjects, medication was discontinued at least 3 weeks before the study. During the untreated ambulatory period, hypertensive patients were defined as those in whom a supine diastolic BP $\geq$95 mm Hg was recorded using a mercury sphygmomanometer. Subjects with evidence of secondary cause of hypertension were excluded on the basis of thorough clinical and laboratory investigations, as previously described.[14] None of the 22 subjects had clinical evidence of congestive heart failure, coronary insufficiency or other occlusive artery disease, valvular heart disease or neurologic impairment.

**Study design:** After informed consent had been obtained, based on a detailed description of the procedure, the patients were investigated at 9 A.M. after 45 minutes of rest in the supine position. Blood pressure was measured using a mercury sphygmomanometer as described elsewhere.[14] An average of 3 measurements was taken for each patient. Phase I of the Korotkoff sounds was used for the determination of systolic BP; phase V was used for the evaluation of diastolic BP. Mean BP was calculated as the sum of diastolic BP plus one-third of the pulse pressure.

Systolic, mean and diastolic BPs were also evaluated using a Dinamap apparatus.[14] Blood pressure was measured every 3 minutes during the last 30 minutes of the resting period. Then carotid femoral pulse wave velocity and noninvasive ambulatory BP monitoring were performed.

**Evaluation of carotid femoral pulse wave velocity:** For the determination of pulse wave velocity in the supine position,[14,15] 2 pulse transducer probes (Electronics for Medicine) were fixed on the skin over the most prominent parts of the common carotid and femoral arteries. The foot-to-foot wave velocity, which contains high frequency information,[10] was measured as the interval between the foot of the carotid and the femoral waves, using a recorder with a paper speed of 150 mm/s. The foot was defined, on extrapolating the wave front downwards, as the intersection of this line with a straight line extrapolation of the last part of the diastolic curve. Measurement of the distance between transducers was then used to calculate pulse wave velocity as the ratio of the distance between the 2 transducers divided by the time interval between the 2 waves. The average of 10 measurements was obtained for each patient. The variability of this method was studied by measuring pulse wave velocity before and after placebo. Measurements were performed at 9 A.M. and 12 noon, and the placebo was administered at 9:15 A.M. in 11 healthy volunteers. Mean arterial pressure and pulse wave velocity did not change significantly; their pre- and post-placebo values were 83 ± 2 and 85 ± 2 mm Hg and 9.7 ± 0.5 and 9.1 ± 0.5 m/s, respectively.

**Noninvasive 24-hour blood pressure monitoring:** Automated BP monitoring was carried out in each patient using a Spacelabs apparatus to measure and record BP and heart rate, as detailed elsewhere.[16,17] Over a full 24-hour period, recordings were performed every 15 minutes from 6 A.M. to 12 midnight and every 30 minutes during the remaining period. The ambulatory monitoring was undertaken for a full day; the patient worked as usual during the day and then went home as usual in the evening.

The reliability of this technique was determined in 32 patients, and was cross-checked with a mercury sphygmomanometer.[18] The microphonic method was tested for accuracy in 16 patients and the oscillometric method in 16 patients; both methods were used with the Spacelabs system. Figure 1 shows the relation between sphygmomanometer and Spacelabs BP measurements. Considerably better regression lines were observed with the microphonic method. For this rea-

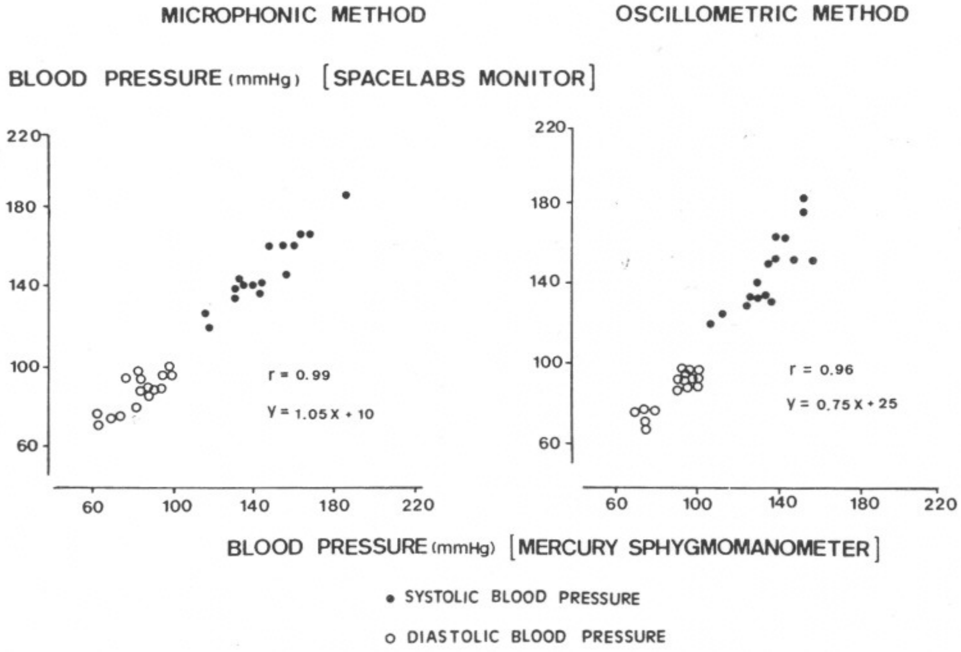

**FIGURE 1. Relations between blood pressure measurements using the mercury sphygmomanometer and the Spacelabs monitor (microphonic and oscillometric methods). For simplicity, systolic and diastolic blood pressures were plotted on the same graph. With the microphonic method, the regression line was not significantly different from the identity line. R = both systolic and diastolic pressure correlation coefficients. Y = ax + b is the regression equation for blood pressure between the Spacelabs monitor and the mercury sphygmomanometer.**

**TABLE I Mean Values of Blood Pressure Measurements**

| | Mercury Sphygmomanometer | Dinamap | 24-Hour Ambulatory Blood Pressure | | | |
|---|---|---|---|---|---|---|
| | | | 24 Hours | 7 A.M. to 10 P.M. | 10 P.M. to 7 A.M. | 8 A.M. to 10 A.M. |
| SBP (mm Hg) | 161 ± 13 | 157 ± 16 | 139 ± 12 | 145 ± 12 | 125 ± 17 | 149 ± 20 |
| DBP (mm Hg) | 101 ± 9 | 99 ± 12 | 93 ± 11 | 96 ± 11 | 84 ± 12 | 100 ± 15 |
| MBP (mm Hg) | 120 ± 11 | 117 ± 13 | 108 ± 10 | 112 ± 10 | 97 ± 12 | 115 ± 16 |
| HR (beats/min) | 75 ± 12 | 73 ± 8 | 80 ± 8 | 83 ± 8 | 70 ± 12 | 82 ± 9 |

Data are mean ± 1 standard deviation.
DBP = diastolic blood pressure; HR = heart rate; MBP = mean blood pressure; SBP = systolic blood pressure.

son, oscillometric recordings were taken into account only if microphonic measurements could not be obtained for technical reasons.

Recordings that showed an inconsistent increase or decrease in systolic or diastolic BP >50 mm Hg without heart rate changes and readings with a calculated pulse pressure of <10 mm Hg were deleted before further data anlaysis. Each full day recording was divided into a diurnal period (from 7 A.M. to 10 P.M.) and a nocturnal period (from 10 P.M. to 7 A.M.), based on a patient diary. The 8 to 10 A.M. period was individualized. Standard statistical evaluations[19] were performed for the study of mean values, standard deviations and correlation coefficients.

## Results

Table I lists the mean values of BP and heart rate (using mercury sphygmomanometer, Dinamap apparatus and ambulatory monitoring). As expected, lower values were observed when the third procedure was used.[16-18] The mean value of carotid femoral pulse wave velocity in hypertensive subjects was 12.2 ± 0.8 m/s. The correlation coefficients of the relation between pulse wave velocity and BP were calculated. Significant correlations were observed only with the Dinamap and the ambulatory BP measurements, not with the mercury sphygmomanometer. For the Dinamap apparatus, the only significant correlation ($r = 0.453$, $p < 0.05$) was observed with systolic BP. For the 24-hour ambulatory BP measurements, significant relations were noted with both systolic ($r = 0.624$, $p < 0.01$) and mean ($r = 0.474$, $p < 0.05$) arterial BP, but not with diastolic BP. Similar results were observed for all but nighttime periods. The best correlation was observed in the daytime for both systolic ($r = 0.685$, $p < 0.001$) and mean ($r = 0.057$, $p < 0.05$) arterial BP. Figure 2 shows the relation between pulse was velocity and systolic BP: while no significant correlation was observed with the mercury sphygmomanometer, a strong positive relation was observed with ambulatory BP measurement. Figure 3 shows a slight positive relation ($r = 0.48$, $p < 0.05$) between pulse wave velocity and heart rate.

## Discussion

Because of the nonlinear stress-strain relation of the arterial wall and its dependence on wall tension, the elastic modulus of any given large artery is a function of intraarterial pressure.[11,12] Since pulse wave velocity is related to wall elasticity, it is also directly related to distending BP.[11,12] For foot-to-foot velocity, it would seem logical that the corresponding pressure that determines wall tension is mainly diastolic BP.[10-12]

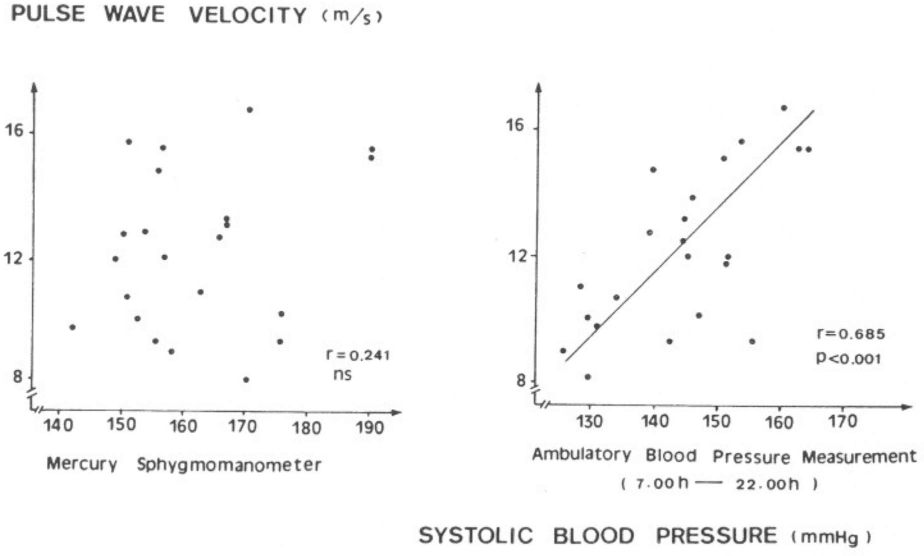

**FIGURE 2. Relations between carotid femoral pulse wave velocity and systolic blood pressure.**

Despite the impressive basic knowledge of arterial hemodynamics, clinical studies have reported varying correlation coefficients for pulse wave velocity and systolic, diastolic and mean BP. Eliakim et al[20] found higher values only in hypertensive subjects older than 60 years. Population studies by Schimmler[21] in German subjects showed a definite increase in pulse wave velocity with mean arterial pressure at all ages, whereas a less definite relation was found by Avolio et al[12] in Chinese subjects in whom age was the main determinant. Studying treated hypertensive patients, Simon et al[22] suggested that the wide variations in pulse wave velocity could reflect the heterogeneity of arterial disease in patients treated for hypertension. Such conflicting results may partly be due to the relatively small number of subjects studied. Another possibility involves the inherent variability in both pulse wave velocity and BP within and between individual subjects.

The present findings clearly show that, in addition to the difficulty in accurately evaluating the foot of the wave front in the determination of pulse wave velocity, the method of BP measurement greatly influences the observed relation between BP and pulse wave velocity. In our small number of hypertensive subjects, no significant correlation was observed between pulse wave velocity and BP evaluated with a mercury sphygmomanometer, as already reported.[12,20,23] However, when serial BP monitoring was performed, a positive relation was observed both with the Dinamap apparatus and with ambulatory BP monitoring. Indeed, the best relation was obtained with the latter procedure, which gave the highest number of BP measurements (Figure 2).

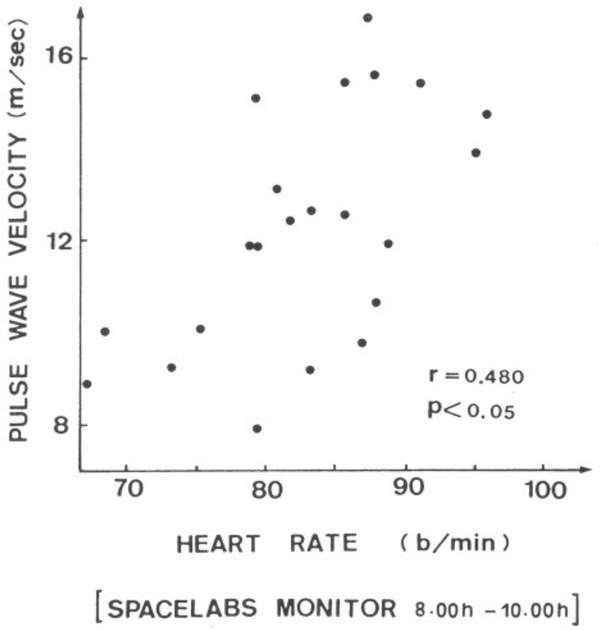

**FIGURE 3. Relation between carotid femoral pulse wave velocity and heart rate.**

Studies of ambulatory BP monitoring have shown that this methodology effectively eliminates the alarm reaction.[24] In addition, the frequent repetition during the day and night, and during exertion and rest, provides a better time integral of the strain exerted on the heart and vessels.[17,24,25] In this regard, the finding that the relation between ambulatory BP and pulse wave velocity exclusively affected the systolic BP is extremely significant.[26] Indeed, whereas diastolic BP is mainly determined by the caliber of small arteries, systolic BP is influenced by independent hemodynamic factors, the principal one being arterial distensibility as evaluated from pulse wave velocity.[9,10] Moreover, during both day and night, BP and arterial distensibility may be affected together by functional factors, such as neurogenic stimuli. In this view, the slight positive correlation observed between heart rate and pulse wave velocity should be noted: the higher the heart rate, the greater the activation of the autonomic nervous system, and the more rigid the arterial wall. In this regard, it is important to note that norepinephrine infusions have been shown to reduce arterial distensibility.[11,12]

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