

Ambulatory arterial stiffness index: rationale and methodology

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Objectives Increased arterial stiffness is associated with the development of cardiovascular disease and may even predict its development at an early stage. Increased pulse pressure is seen as a marker of increased arterial stiffness and can be readily measured by ambulatory blood pressure monitoring. We propose another surrogate measure of arterial stiffness derived from ambulatory blood pressure monitoring that may predict cardiovascular mortality over and above pulse pressure, namely, the dynamic relationship between diastolic and systolic blood pressure over 24 h – the ambulatory arterial stiffness index.

Methods Using all blood pressure readings over the 24-h period from 11 291 (5965 women; mean age 54.6 years) patients referred for ambulatory blood pressure monitoring to a blood pressure clinic, diastolic blood pressure was plotted against systolic blood pressure, and the regression slope was calculated; ambulatory arterial stiffness index was defined as one minus this regression slope.

Results Both ambulatory arterial stiffness index and pulse pressure were higher in women (0.42 vs. 0.40 and 57.0 vs. 55.3 mmHg, respectively). For the entire group, the

correlation between ambulatory arterial stiffness index and pulse pressure was 0.5.

Conclusions Ambulatory arterial stiffness index is a new measure that is readily available from ambulatory blood pressure monitoring and may provide added prognostic information for cardiovascular outcome. *Blood Press Monit* 11:103–105 © 2006 Lippincott Williams & Wilkins.

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Introduction

Ambulatory blood pressure monitoring (ABPM) is increasingly used in the management of hypertensive patients [1]. Current guidelines for the management of hypertension recommend the technique for identifying patients with white-coat hypertension. [2] Arterial stiffness is a strong predictor of cardiovascular complications [3–9], but detailed measurement requires special equipment and trained observers, thus limiting its use in clinical practice.

The ejection of blood into the aorta generates a pressure wave that is propagated to other arteries throughout the body. Peak systolic blood pressure and end-diastolic blood pressure are used to define the pulsatile haemodynamic load. In individuals with elastic arteries, changes in systolic and diastolic blood pressure occur in parallel throughout the blood pressure range. In individuals with less compliant arteries, increases in the distending pressure, above a certain threshold, are associated with a greater change in systolic pressure than in diastolic pressure. In those with very stiff vessels, systolic pressure

rises sharply with distending pressure, whereas diastolic pressure may decrease. The relationship of arterial stiffness and distending pressure is not a linear one – as mean arterial pressure increases, stiffness increases exponentially [10]. Mean arterial pressure shows considerable diurnal variability, usually increasing with activity and declining with rest and sleep. On the basis of these haemodynamic principles, we hypothesized that the dynamic relationship between diastolic and systolic blood pressure over 24 h would provide a measure of the stiffness of the arterial wall.

Methods

Study population

From 1980 to 2002, we enrolled 14 414 study participants into the Dublin Mortality Outcome Study [1]. We excluded 3123 participants, because ABPM readings were less than 10 during daytime or 5 during nighttime ($n = 2612$), or because cardiovascular risk factors had not been recorded at baseline ($n = 433$), or because vital status could not be ascertained ($n = 78$). The total number of participants included in the present analysis

was 11 291. The Ethics Committee of Beaumont Hospital approved the study.

Ambulatory blood pressure measurement

Validated oscillometric 90202 or 90207 SpaceLabs recorders were programmed (Spacelabs, Wokingham, Berkshire, UK) to obtain blood pressure readings at 30-min intervals throughout the day [11,12]. In keeping with the Seventh Joint National Committee guidelines [2], hypertension was defined as a daytime (10:00–20:00 h) ABPM averaging at least 135 mmHg systolic or 85 mmHg diastolic pressure. For database management, all clinical data were transferred into the dabl Cardiovascular software package (dabl Ltd, Dublin, Ireland; www.dabl.ie)

Calculation of ambulatory arterial stiffness index

The regression slope of diastolic on systolic blood pressure from unedited 24-h recordings was computed for each participant. AASI was defined as one minus the regression slope (Fig. 1). The stiffer the arterial tree, the closer the regression slope and AASI are to zero and one, respectively.

Statistical analysis

The analyses were performed using SAS software, version 9 (SAS Institute Inc, Cary, North Carolina, USA). The linear regression relationship was calculated using the PROC REG function for each individual. The regression line was not forced through zero. We compared means and proportions by the large sample z -test and the χ^2 -statistic, respectively.

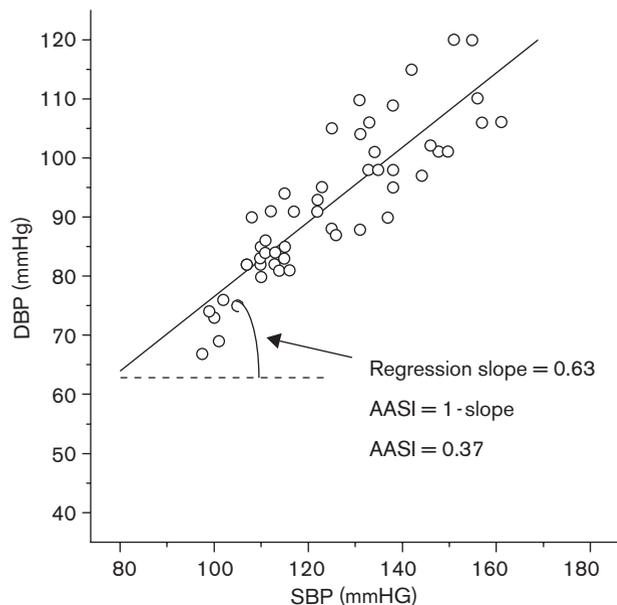
Results

Mean (\pm SD) age at enrolment was 54.6 ± 14.6 years. Mean AASI for the entire group was 0.41 (5th to 95th percentile interval: 0.15–0.68) while mean PP was 56.4 mmHg (40.4–79.6 mmHg). Table 1 lists the baseline characteristics of the 11 291 participants by sex. The two indexes of arterial stiffness were significantly higher in women than in men (0.42 vs. 0.40, $P < 0.0001$ and 57.0 vs. 55.3 mmHg, $P < 0.0001$, respectively). Both mean 24-h systolic and diastolic blood pressures were higher in men and the prevalence of cardiovascular risk factors were higher among men than women.

Discussion

The last decade has seen increased interest in the mechanical interaction between the heart and the arterial system. In particular, it has been suggested that increased arterial stiffness is associated with the development of cardiovascular disease and may even predict its development at an early stage before vascular lesions induce symptoms [3,4]. The reasons for this association are not fully understood, although it has been known for some time that pulse pressure is affected by the distensibility of the arterial system, its dimensions and the presence of wave reflections. Accordingly, renewed attention has been

Fig. 1



Derivation of the ambulatory arterial stiffness index (AASI) from a 24-h ambulatory blood pressure recording in one participant, whose 24-h blood pressure was 129 mmHg for systolic blood pressure and 95 mmHg for diastolic blood pressure.

Table 1 Baseline characteristics of the study population according to sex

	Women (n=5.965)	Men (n=5.326)
Age (years)	54.9 (14.9)	53.5 (14.2)*
24-h BP recordings		
Systolic pressure (mmHg)	137.7 (17.9)	140.1 (17.0)*
Diastolic pressure (mmHg)	80.5 (11.1)	84.7 (11.6)*
Pulse rate (bpm)	72.6 \pm 7.6	71.9 \pm 9.6
Indexes or arterial stiffness		
Pulse pressure	57.0 (13.3)	55.3 (11.2)*
AASI	0.42 (0.16)	0.40 (0.16)*
Risk factors		
Smoking	19.8	20.9
Hypertension [6]	74.1	77.2*
Diabetes mellitus	6.6	8.8*
Previous CV disease	10.6	15.3*
Body mass index (kg/m ²)	26.8 (5.3)	27.3 (3.9)*

Values are mean (SD) or percentages of participants (%). The asterisk indicates a significant sex difference ($P < 0.01$). BP, blood pressure; AASI, ambulatory arterial stiffness index; CV, cardiovascular.

directed at methods of measuring arterial elasticity, either directly or by way of surrogate measures.

The change of vascular compliance with age with the resultant increase in systolic blood pressure and decline in diastolic blood pressure is well recognized [13]. Hence, increased pulse pressure is seen as a marker of reduced compliance and is associated with a worse outcome in the older adult [13]. Compliance of arteries depends on arterial volume and the elastic properties or distensibility

of arterial walls. The relationship between distending pressure and arterial distensibility is not a linear one. The capacity of large arteries to expand at higher distending pressures is reduced with a resultant increase in systolic blood pressure. This lower compliance means that at lower distending pressures, systolic and diastolic blood pressures would show parallel changes. At higher distending pressures, however, above a certain threshold for an artery, a greater rise in systolic blood pressure than in diastolic blood pressure might be anticipated but might not be apparent from the mean pulse pressure.

A number of methodologies exist for measuring vascular compliance, such as pulse wave velocity or the augmentation index. Their merits and failings are being debated, however, and dedicated equipment and trained personnel are required. The results attained are also dependent on the ambient pressure. Changing the blood pressure may in fact alter the reading for arterial stiffness. We propose a novel method for estimating arterial stiffness from ABPM. As outlined in a research paper published in 1914, the relationship between diastolic and systolic blood pressure in an individual may give an insight into arterial function [14]. This relationship can be quantified using the regression of all diastolic pressures measured during 24 h of monitoring against systolic pressures.

In this study, we have shown that AASI can be easily calculated in a large group of hypertensive patients. Similar to other measures of arterial stiffness, there are higher readings in female patients presumably because of shorter stature and systolic augmentation. AASI has been shown to correlate with other surrogate measures of arterial stiffness [15]. The data also suggest that AASI may provide added prognostic information above that of mean blood pressure for cardiovascular mortality [16,17]. In conclusion, AASI, a new measure readily available noninvasively from ABPM, provides additional novel information on the risk stratification of cardiovascular patients.

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