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Arterial Stiffness as Underlying Mechanism of Disagreement Between an Oscillometric Blood Pressure Monitor and a Sphygmomanometer

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Abstract—Oscillometric blood pressure devices tend to overestimate systolic blood pressure and underestimate diastolic blood pressure compared with sphygmomanometers. Recent studies indicate that discrepancies in performance between these devices may differ between healthy and diabetic subjects. Arterial stiffness in diabetics could be the underlying factor explaining these differences. We studied differences between a Dinamap oscillometric blood pressure monitor and a random-zero sphygmomanometer in relation to arterial stiffness in 1808 healthy elderly subjects. The study was conducted within the Rotterdam Study, a population-based cohort study of subjects aged 55 years and older. Systolic and diastolic blood pressure differences between a Dinamap and a random-zero sphygmomanometer were related to arterial stiffness, as measured by carotid-femoral pulse wave velocity. Increased arterial stiffness was associated with higher systolic and diastolic blood pressure readings by the Dinamap compared with the random-zero sphygmomanometer, independent of age, gender, and average mean blood pressure level of both devices. The β -coefficient (95% CI) was 0.25 (0.00 to 0.50) mm Hg/(m/s) for the systolic blood pressure difference and 0.35 (0.20 to 0.50) mm Hg/(m/s) for the diastolic blood pressure difference. The results indicate that a Dinamap oscillometric blood pressure device, in comparison to a random-zero sphygmomanometer, overestimates systolic and diastolic blood pressure readings in subjects with stiff arteries. (*Hypertension*. 2000;36:484-488.)

Key Words: blood pressure monitoring ■ oscillometry ■ sphygmomanometry ■ arterial stiffness

Automatic oscillometric blood pressure devices are frequently used to measure blood pressure. Several studies, evaluating their performance in comparison with a Hawksley random-zero or conventional sphygmomanometer, showed that oscillometric devices tend to overestimate systolic blood pressure (SBP) and underestimate diastolic blood pressure (DBP) compared with sphygmomanometers.¹⁻⁴ Recent studies indicate that differences in performance between these devices may diverge between healthy and diabetic subjects.⁵⁻⁷ One study, comparing a Dinamap 8100 oscillometric device with a Hawksley random-zero sphygmomanometer in diabetic subjects, found that the Dinamap overestimated SBP <118 mm Hg and underestimated SBP >152 mm Hg, while DBP was underestimated over the whole range of pressures.⁵ Another study compared a SpaceLabs 90207 oscillometric device with a sphygmomanometer in diabetic subjects and healthy controls. The SpaceLabs device overestimated SBP in both diabetic subjects and controls, but the overestimation was more pronounced in the diabetic subjects. DBP was underestimated in both groups but was less pronounced in diabetic subjects.^{6,7}

An oscillometric blood pressure device determines blood pressure by detecting a sequence of oscillations in cuff pressure while the pressure is reduced.⁸ Since diabetic patients have stiffer arteries than nondiabetic subjects,⁹ arterial stiffness could be the underlying mechanism of the more pronounced differences between oscillometric devices and sphygmomanometers in this group. We evaluated determinants of differences between an oscillometric blood pressure device and a sphygmomanometer in a large population-based cohort of elderly subjects.

Methods

Study Design

This study was conducted within the Rotterdam Study. The Rotterdam Study is a population-based cohort study that seeks to assess the occurrence of and risk factors for chronic diseases in the elderly. The rationale and design of the Rotterdam Study have been described in detail elsewhere.¹⁰ For the present analyses, all measurements took place during a follow-up examination between March 1997 and January 1999. Blood pressure measurements taken by a Dinamap and a random-zero blood pressure monitor were compared in the first 1808 subjects who participated in the follow-up examination. The

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Medical Ethics Committee of Erasmus University approved the study, and written informed consent was obtained from all participants.

Measurement of Blood Pressure

Blood pressure was measured in a fixed order, first with a Dinamap xl vital signs monitor (Critikon Inc) and approximately 15 minutes later with a Hawksley MKII random-zero sphygmomanometer (Hawksley and Sons Ltd). A physician took all Dinamap readings with the subject in the supine position. An experienced research nurse, who was not aware of Dinamap recordings, took all random-zero readings while the subject was sitting. Blood pressure was measured twice at the right arm after 5 minutes of rest; cuff size as recommended by the manufacturer was used on all occasions. For random-zero recordings, Korotkoff sounds phase 1 and 5 were taken for SBP and DBP, respectively. Readings were recorded to the nearest 2 mm Hg.

Measurement of Arterial Stiffness

Arterial stiffness was assessed by carotid-femoral pulse wave velocity (PWV). The time delay between the rapid upstroke of the feet of simultaneously recorded pulse waves in the carotid artery and the femoral artery was measured with an automatic device (Complior, Colson).¹¹ The distance traveled by the pulse wave between carotid and femoral artery was measured over the surface of the body with a tape measure. PWV was calculated as the ratio of the distance traveled by the pulse wave and the foot-to-foot time delay and expressed in meters per second. To cover a complete respiratory cycle, the average of at least 10 successive measurements was used in the analyses.

Control Study

The population-based study was performed on a large number of subjects, thereby optimizing the opportunity to study determinants of differences between blood pressure-measuring devices. However, several aspects in the design of the population-based study may create differences between measurements obtained by different blood pressure devices. We conducted a second study to examine whether observed differences between the 2 monitors in the population-based study were due to these nonoptimal design aspects. To optimize conditions, this control study was performed according to the British Hypertension Society protocol part II validation procedures in elderly subjects.¹² Both devices were compared in 2 groups of 28 subjects, selected from the 1808 subjects of the population-based study. Selection was based on their SBP and DBP differences, age, and arterial stiffness status, as defined by PWV, observed in the population-based study. One group comprised subjects with SBP and DBP differences between devices, age, and PWV all below the mean of the respective distributions in the population-based study (nonstiff group), and the other group comprised subjects with these characteristics all above the mean of the respective distributions in the population-based study (stiff group). This selection resulted in assigning subjects with lower or slightly higher Dinamap readings than random-zero readings to the group referred to as the nonstiff group and assigning subjects with considerably higher Dinamap readings than random-zero readings to the group referred to as the stiff group. Thus, selection was made on the basis of both arterial stiffness status and blood pressure differences between devices. Under the assumption that there are no unknown alternative explanations for the association between arterial stiffness and differences between the devices, observing the same difference between the devices in a new study, in which nonoptimal design aspects are removed, indicates that the difference can be truly ascribed to arterial stiffness. A sequential comparison was performed on the right arm with a single cuff. The length of the cuff was chosen to be sufficient to encircle 80% of the subject's arm circumference. A conventional sphygmomanometer was included in the comparison. The 3 different devices were used alternately. A total of 3 blood pressure measurements, 2 minutes apart, were performed with each device while the subject was sitting, without prior rest. The order of

TABLE 1. Characteristics and Blood Pressure Values of the Study Population of the Population-Based Study (Rotterdam Study, 1997–1999)

	Population-Based Study (n=1808)
Age (range), y	73 (61–95)
Men, %	39
PWV, m/s	14.0 (3.2)
Random-zero	
SBP	141 (20)
DBP	74 (11)
Dinamap	
SBP	152 (23)
DBP	78 (11)

Values are mean (SD) unless indicated otherwise. Blood pressure values are expressed in millimeters of mercury.

the device was determined by randomization with a die. One experienced research assistant, who was unaware of the research question, performed all measurements. For readings with a sphygmomanometer, Korotkoff sounds phase 1 and 5 were taken for SBP and DBP, respectively. Readings were recorded to the nearest 2 mm Hg. The same equipment was used throughout the study period.

Statistical Analysis

In the population-based study, blood pressure values are based on the mean of 2 successive readings. Differences are presented as Dinamap minus random-zero values. A paired *t* test was used to evaluate whether differences between random-zero and Dinamap methods were significantly different from zero. Determinants of the SBP and DBP difference were evaluated by multiple linear regression analyses with SBP or DBP difference as dependent variable, adjusted for average mean blood pressure level of both devices (Dinamap+random-zero/2). This analysis was done for the total cohort and in strata of gender. Subsequently, mean SBP and DBP differences were calculated per quartile of PWV, adjusted for age, gender, and average mean blood pressure level of both devices, with ANCOVA. A test for trend was performed with multiple linear regression analyses, with quartiles of PWV as ordinal variable.

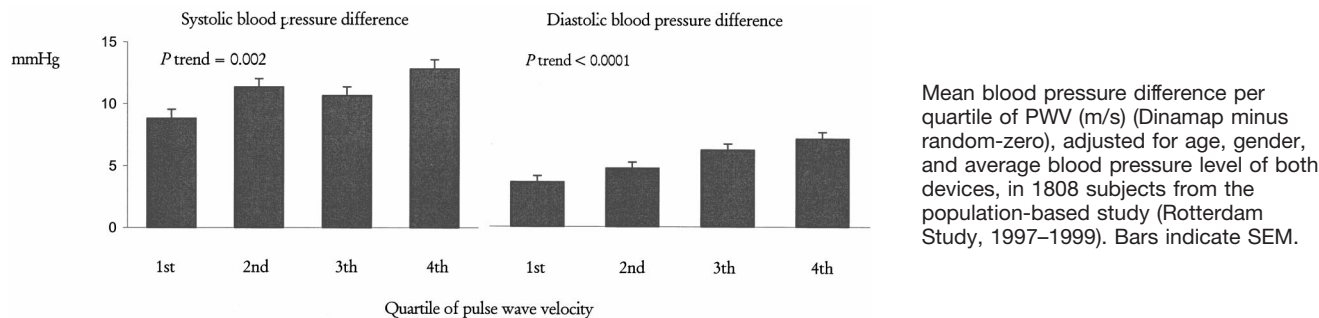
In the control study, blood pressure values were based on the mean of 3 readings with each device. Differences are presented as Dinamap minus random-zero values, Dinamap minus conventional sphygmomanometer values, and random-zero minus conventional sphygmomanometer values. A paired *t* test was used to evaluate whether observed differences were significantly different from zero. A 2-sample *t* test was used to evaluate blood pressure differences between the nonstiff group and the stiff group within and between devices.

A difference was considered to be statistically significant when the 2-sided *P* value was <0.05. All analyses were performed with the statistical package SPSS 8.0 for Windows 95 (SPSS Inc).

Results

Population-Based Study

Characteristics and blood pressure values of the study population of the population-based study are shown in Table 1. Mean SBP difference (95% CI) between the Dinamap and random-zero methods was 10.9 (10.2 to 11.6) mm Hg, and mean DBP difference was 4.8 (4.3 to 5.1) mm Hg. A positive difference indicates that the Dinamap reading was higher than the random-zero reading. Age was a significant determinant for both the SBP and DBP differences. The β -coefficient



(95% CI) was 0.105 (0.003 to 0.207) mm Hg per year increase in age for the SBP difference and 0.183 (0.120 to 0.246) mm Hg per year increase in age for the DBP difference, adjusted for gender and average mean blood pressure level of both devices. Subsequent analyses showed that arterial stiffness was a significant determinant for both the SBP and DBP difference, adjusted for age, gender, and average mean blood pressure level of both devices. The β -coefficient (95% CI) was 0.25 (0.00 to 0.50) mm Hg per 1 m/s increase in PWV for the SBP difference and 0.35 (0.20 to 0.50) mm Hg per 1 m/s increase in PWV for the DBP difference. The positive regression coefficients indicate higher SBP and DBP readings by Dinamap compared with the random-zero device with increasing age and increasing arterial stiffness. Results were the same for men and women separately (data not shown). In the Figure, the association between arterial stiffness and blood pressure differences is shown in quartiles of the PWV distribution.

Control Study

The characteristics of the study population of the control study are shown in Table 2. Observed differences in all comparisons, for both the stiff and nonstiff group, were significantly different from zero, except the DBP difference between Dinamap and the random-zero device in the stiff group and the SBP difference between Dinamap and a conventional sphygmomanometer in the stiff group (Table 3). The direction of SBP and DBP differences varied, and agreement between monitors was sometimes better in the stiff group than in the nonstiff group. However, in agreement with the population-based study, there was a general trend toward more positive SBP and DBP readings in the stiff group than in the nonstiff group by the Dinamap compared with both sphygmomanometers. In the comparison of Dinamap with the random-zero device, the SBP and DBP differences were significantly more positive in the stiff group than in the nonstiff group. In the comparison of Dinamap with a conventional sphygmomanometer, the SBP difference was borderline significantly more positive and the DBP difference was significantly more positive in the stiff group compared with the nonstiff group. In the comparison of random-zero with a conventional sphygmomanometer, the SBP and DBP differences were not significantly different between the nonstiff and stiff groups.

Discussion

Our results show that arterial stiffness is associated with an overestimation of SBP and DBP by a Dinamap oscillometric

blood pressure device compared with a Hawksley random-zero sphygmomanometer. The control study, conducted according to the British Hypertension Society protocol, confirms that arterial stiffness is a determinant of overestimation of SBP and DBP by the Dinamap compared with a random-zero sphygmomanometer in subjects with stiff arteries.

Some aspects of the study need to be discussed. First, we adjusted all analyses for mean blood pressure level (average of both devices) because PWV is highly dependent on blood pressure, and the difference between the devices increased with increasing blood pressure level (data not shown). Second, PWV was calculated using the distance between carotid and femoral artery as distance associated with the time delay between the pulse waves. This distance is longer than the "true" distance, resulting in overestimation of the pulse wave velocity. Because variations in anatomy are limited, this overestimation can be considered similar for all subjects and therefore will not have seriously affected our results. Third, we related carotid-femoral PWV to blood pressure difference between devices measured at the brachial artery. We thereby assumed that vessel wall stiffness of the carotid-femoral vessel bed is representative of brachial arterial stiffness. It is known, however, that there is a reasonable heterogeneity among vessel wall properties of different arterial regions.^{13,14}

TABLE 2. Characteristics and Blood Pressure Values of the Study Population of the Control Study (Rotterdam Study, 1997–1999)

	Nonstiff Group (n=28)	Stiff Group (n=28)
Age (range), y	68 (62–76)	83 (77–91)
Men, %	14	46
PWV, m/s	12.1 (1.1)	18.0 (2.7)
Random-zero		
SBP	121 (14)	131 (17)*
DBP	74 (9)	72 (12)
Dinamap		
SBP	129 (17)	143 (20)*
DBP	70 (10)	73 (12)
Conventional sphygmomanometer		
SBP	131 (14)	143 (20)*
DBP	80 (8)	76 (13)

Values are mean (SD) unless indicated otherwise. Blood pressure values are expressed in millimeters of mercury.

* $P < 0.05$, stiff group vs nonstiff group.

TABLE 3. Student's *t* Test for Equality of Mean SBP and DBP Differences Between Dinamap and Random-Zero, Dinamap and Conventional Sphygmomanometer, and Random-Zero and Conventional Sphygmomanometer Methods in the Nonstiff vs the Stiff Group of the Control Study (Rotterdam Study, 1997–1999)

	Group		Difference	<i>P</i>
	Nonstiff	Stiff		
Dinamap—random zero				
SBP	8.0	12.7	−4.7	0.01
DBP	−4.2	1.3	−5.5	0.002
Dinamap—conventional sphygmomanometer				
SBP	−2.5	0.3	−2.8	0.077
DBP	−9.8	−3.1	−6.7	<0.001
Random zero—conventional sphygmomanometer				
SBP	−10.5	−12.4	1.9	0.22
DBP	−5.5	−4.4	−1.1	0.36

Values are expressed in millimeters of mercury.

To the best of our knowledge, there are no studies comparing vessel wall properties of brachial artery with those of the carotid-femoral vessel bed, which makes it difficult to accurately assess the validity of our assumption. However, we assume that misclassification in brachial arterial stiffness status is nondifferential and thus, if present, will have resulted in an underestimation of the association.

Design aspects of the population-based study may have created the observed differences between devices. Examples of such design aspects are the fixed order in which the device were used, the subject's body position during measurement (sitting versus supine), and the observer (nurse versus doctor). The expected effect of these aspects on differences between the devices, however, does not always correspond with observed differences. For example, it is known that blood pressure measured in the sitting position is generally higher than blood pressure measured in the supine position.^{15,16} The difference in body position in the population-based study cannot explain our results since Dinamap blood pressures were higher than random-zero blood pressures and subjects were in the supine position during Dinamap recordings and were sitting during random-zero recordings. The design aspects of the population-based study also cannot explain that the blood pressure differences between devices are dependent on arterial stiffness status, which is confirmed in the control study.

An alternative interpretation of our findings is that increased arterial stiffness leads to underestimation of SBP and DBP by the random-zero sphygmomanometer compared with the Dinamap. Previous studies indicate that the random-zero device underestimates SBP and DBP compared with a conventional sphygmomanometer.¹⁷ In agreement with this, we found an underestimation of SBP and DBP measured by the random-zero device in comparison with the conventional sphygmomanometer in both the stiff and nonstiff groups of the control study. However, between the stiff and nonstiff group, no significant difference in blood pressure differences between devices was observed, indicating that the underestimation by the random-zero device was not related to arterial

stiffness. The underlying mechanism by which blood pressure is measured by a sphygmomanometer is also not compatible with this alternative interpretation. Current thinking on the origin of Korotkoff sounds during sphygmomanometry is that they might be generated by movement of the vessel wall.¹⁸ Increased arterial stiffness could diminish vessel wall movements, resulting in decreased loudness of Korotkoff sounds.¹⁸ This would lead to lower SBP but higher DBP readings with a sphygmomanometer in subjects with stiff arteries. Since we found both lower SBP and DBP by the random-zero method compared with the Dinamap, this alternative explanation is only compatible with the observed difference in SBP and therefore unlikely.

Previous studies showed that oscillometric devices tend to overestimate SBP and underestimate DBP compared with conventional sphygmomanometers.^{1–4} In the population-based study, Dinamap overestimated both SBP and DBP compared with the random-zero device. The relatively old age of this study population could be the reason for finding an overestimation of DBP, since increasing age was a determinant of overestimation of SBP and DBP by Dinamap. In agreement with the previous studies, we found an overestimation of SBP and an underestimation of DBP by Dinamap compared with the random-zero device in younger subjects with distensible arteries (nonstiff group) in the control study. In comparison with a conventional sphygmomanometer, Dinamap underestimated both SBP and DBP in the nonstiff group. This underestimation became less in the stiff group. Although not in agreement with previous studies, it supports our hypothesis that a Dinamap uniformly gives more positive blood pressure readings in subjects with stiff arteries.

Our results with respect to stiffness are in accord with a previous study that found more overestimation of SBP and less underestimation of DBP in diabetic subjects compared with healthy controls by a SpaceLabs device compared with a conventional sphygmomanometer.⁷ It is well known that diabetic subjects have stiffer arteries than nondiabetic subjects.⁹ Increased arterial stiffness in diabetic subjects might be the underlying mechanism of the observed difference be-

tween the devices. Another study evaluated differences between a Dinamap 8100 and a random-zero sphygmomanometer in diabetic subjects and found an overestimation of SBP at low SBP values, an underestimation of SBP at higher SBP levels, and an underestimation of DBP at all DBP values by Dinamap compared with the random-zero device.⁵ This is discordant with our results. We observed an increasing difference between the Dinamap and the random-zero sphygmomanometer with increasing blood pressure level. If arterial stiffness is indeed a determinant of SBP difference, this is what one would expect to find since SBP rises when arteries become stiffer.

The mechanism by which arterial stiffness leads to higher SBP and DBP readings by Dinamap is not clear. It might be explained by changes in oscillograms of subjects with stiff arteries. The algorithm by which Dinamap determines SBP and DBP from an oscillogram is not known publicly. Therefore, it is not feasible to speculate about the effect of changes, observed in oscillograms of subjects with stiff arteries, on blood pressure determination by Dinamap.

Accurate blood pressure determination and diagnosis of hypertension is essential in subjects with a compromised cardiovascular system. Therefore, more studies are needed to elucidate the effects of arterial characteristics on blood pressure measurement by oscillometric devices. Most subjects participating in validation studies are healthy volunteers. Elderly volunteers might have relatively young arterial systems. We suggest including special subgroups such as subjects with arterial stiffness, advanced atherosclerosis, hypertension, cardiovascular disease, or diabetes in validation studies of blood pressure-measuring devices.

In conclusion, the results of our study suggest that arterial stiffness is a determinant of higher SBP and DBP readings by a Dinamap oscillometric blood pressure device compared with sphygmomanometers.

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