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Comparison of two techniques for measuring pulse wave velocity and central blood pressure

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Abstract Pulse wave velocity (PWV) is an important parameter in the assessment of overall cardiovascular risk and there is well documented predictions of mortality in special groups of patients. Several methods are available for measuring the velocity and other parameters of the pulse wave. Our aim was to assess the comparability of two methods; applanation tonometry, which is used by the SphygmoCor device and oscillometry employed by the Arteriograph system. Published data on their comparability are contradictory. Thirty-three patients of both sexes were examined in the study. Mean PWV was significantly higher with Arteriograph than SphygmoCor ($10.2 \text{ m/s} \pm 3.9$ vs. $8.9 \text{ m/s} \pm 2.5$) and Aix was significantly higher with Arteriograph than SphygmoCor too (29.3 ± 16.3 vs. 21.2 ± 12.6). The lack of agreement between the two methods is confirmed also by the Bland–Altman plot. Due to working principle of the Arteriograph possible conclusion is that parameters provided by the Arteriograph are the measures of brachial stiffness and not aortic stiffness. However, the method used by the Arteriograph is definitely much simpler and more time-efficient than applanation tonometry used by the SphygmoCor device.

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Introduction

Pulse wave velocity (PWV) is an indicator of structural changes of the aorta and large vessels. In the current guidelines for the management of patients with arterial hypertension,^{1–3} PWV is an important parameter in the

assessment of overall cardiovascular risk and there is well documented predictions of mortality in special groups of patients, eg. elderly in patients with end-stage renal disease, diabetes mellitus or hypertension and in the general population as well⁴ and is correlated with coronary heart disease.⁵ Measurement of carotid-femoral pulse wave velocity is the only non-invasive method which is accurate enough to be used as a diagnostic procedure in a clinical setting. High values indicate stiffness of arteries.¹

Augmentation and the augmentation index (Aix) are being used as parameters of wave reflection. They are a direct

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measure of wave reflection. The effect of wave reflection on the aortic systolic pressure peak can be described as augmentation. Dividing the augmentation pressure by the pulse pressure gives the Alx. It has also been shown that Alx is closely correlated with the cardiovascular risk and correlates with left ventricular mass even in normotensive subjects.⁶ Both PWV and augmentation provide extensive information on the arterial vascular system.

Several methods are available for measuring the velocity and other parameters of the pulse wave (central blood pressure, Alx). The oldest is applanation tonometry, which is used by the SphygmoCor device (At Cor Medical, Australia). Pulse wave velocity is calculated as the ratio of the distance between carotid artery and femoral artery, and the pulse transit time from one location to the other. Another method is oscillometry employed by the Arteriograph system (ColsonMed, Hungary). This device measures the pulse wave at one single location using brachial cuff that is overinflated to 35 mmHg over systolic blood pressure. The time difference between the first systolic wave and the second reflected wave is used as a transit time. Pulse wave velocity can be calculated as the ratio of travelled distance between jugulum and symphysis over transit time.

Our aim was to assess the comparability of these two methods since the published data on their comparability are contradictory.

Methods

All measurements were performed by the same technician in the same room at a constant temperature and were unaffected by external environmental influences.

Blood pressure (BP) was measured at the upper arm using an OMRON 7051T oscillometric monitor in accordance with the international and national guidelines.^{2,3} The first measurement in each patient was performed by applanation tonometry, as a standard method, using the SphygmoCor device. Pulse curves were recorded over the radial, carotid and femoral arteries, and the ECG was recorded simultaneously. The pulse pressure curve measured at the radial artery was calibrated against an oscillometrically measured upper-arm blood pressure. The augmentation index (Alx) was then determined by calculating the aortic pressures by means of a transfer function.⁷ PWV was calculated from the pulse waves curves recorded over the carotid and femoral arteries sequentially and the simultaneously obtained ECG tracings. The distance between the carotid registration site and the femoral arterial registration site was then determined, and the delay of the pulse wave relative to the QRS complex in the ECG are the basis for PWV calculation.⁸

The measurement with the Arteriograph was performed directly after the initial measurement. In this method, a cuff of appropriate size is wrapped around the upper arm and overinflated to 35 mmHg over the systolic blood pressure. Oscillations in the cuff are a reflexion of oscillations of the brachial artery. The principle of the oscillometric method is based on plethysmography and registers pulsatile pressure changes in an artery. The software of the Arteriograph decomposes the early, late systolic and diastolic waves and also determines the onset and the peaks of the waves and

than calculates PWV, assuming that the measured external distance from jugulum to symphysis is an approximation of the distance to the reflection site. The augmentation index corresponds to the pressure difference between the first and second wave in relation to the pulse pressure.⁹

The study was conducted on random patients scheduled for PWV evaluation. Thirty-three patients of both sexes were examined in the study. As shown in Table 1, the subjects differed considerably in age, body mass index (BMI) and BP.

All values are given as a mean and standard deviation. Differences between two groups were tested with the *t*-test. Less than 5% risk was taken to be significant. The variance was plotted according to Bland and Altman.¹⁰

Results

Comparison of the results of the PWV measurements (made with the Arteriograph and the SphygmoCor device) is presented in Table 2. The difference between the two methods is statistically significant both for PWV and for the calculated Alx values. The lack of agreement between the two methods is confirmed also by the Bland–Altman plot, both for PWV and Alx (Figs. 1 and 2). The average discrepancy between the results obtained with the two methods is greater for Alx than for PWV.

Discussion

Pulse wave velocity is a clinically accepted index for evaluation of aortic stiffness as a factor of cardiovascular risk.¹¹ There is increasing evidence that central blood pressure is an important clinical parameter. It is affected by various drug regimens used in the treatment of hypertension and is not always equal to brachial BP.^{12,13} The recent publication of reference values for PWV and central BP¹⁴ has increased the clinical applicability of these measurements.

Applanation tonometry is currently the most widely used method for non-invasive evaluation of the shape of the pulse wave curve and calculation of parameters relevant for estimation of central BP. The method is technically very demanding. The subject must rest before the measurement, and the examiner must position the probe correctly

Table 1 Basic characteristics of the study subjects.

	N	Minimum	Maximum	Mean	Std. deviation
Age	33	24.00	85.00	54.4242	15.43946
BMI	33	19.94	42.53	28.8941	4.35818
SBP (mmHg)	33	97	192	143.79	20.320
DBP (mmHg)	33	60	116	81.79	13.233
PP (mmHg)	33	35.00	101.00	62.0000	15.04992

BMI: body mass index; SBP: systolic blood pressure; DBP: diastolic blood pressure; PP: pulse pressure.

Table 2 Comparison of results for pulse wave velocity.

	Mean	N	SD	Sig.
SphygmoCor PWV	8.916	32	2.5391	0.004
Arteriograph PWV	10.2075	32	3.03080	
SphygmoCor Alx	21.13	32	12.569	0.000
Arteriograph Alx	29.2800	32	16.31157	

PWV: pulse wave velocity; Alx: augmentation index.

over the artery and use the right amount of pressure to obtain adequate pulse wave recordings. Applying excessive pressure over the carotid artery may be fatal if an unstable atherosclerotic plaque happens to be present at that site. The oscillometric method used by the Arteriograph is much simpler to perform and requires less experience on the part of the examiner. Correct placement of the cuff on the upper arm is essential for accurate measurements. The examination is brief and provides simultaneous measurement of brachial BP, which must be determined separately when applanation tonometry is used.

Published data on the comparability of these two methods for the measurement of PWV and BP in the aorta differ considerably among studies. Some authors observed satisfactory agreement between the results¹⁵ and others did not.¹⁶ The advantages and shortcomings of each method are described in the literature.¹⁷ Our data suggest that the two methods are not interchangeable. It seems that the aortic PWV measured and calculated by Arteriograph represents PWV in the arm rather than aorta. Inflation of the brachial cuff to a suprasystolic pressure is the basic working principle of the Arteriograph which leads to an amplification of the second peak in the brachial pressure curve which is hardly noticeable in normal conditions.¹⁸ We agree with the explanation that measured wave is predominantly the result of waves traveling back and forth in the brachial artery reflected distally on the occluded cuff and proximally on the open-end reflection of the aortic junction.¹⁹ In some earlier studies it was shown that brachial PWV is higher than aortic, depending on blood

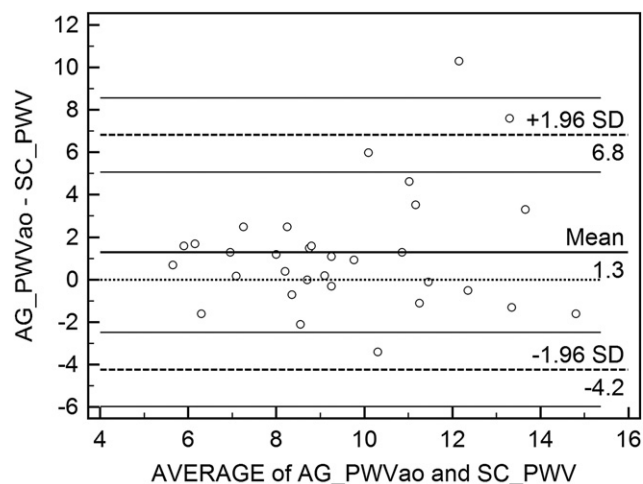


Figure 1 Bland–Altman plot of differences between the results for pulse wave velocity obtained with two methods.

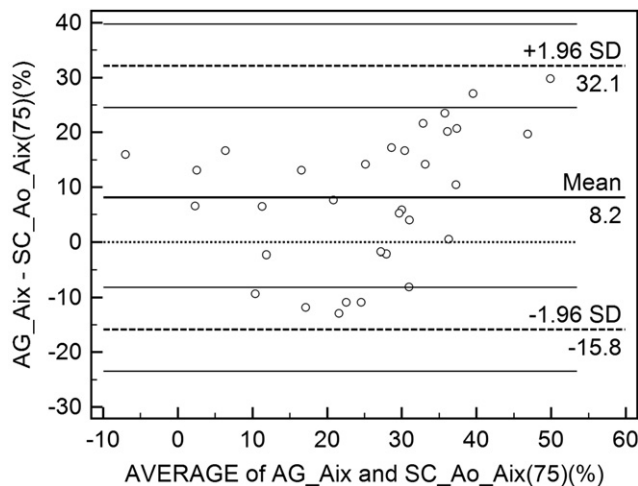


Figure 2 Bland–Altman plot of differences between augmentation index values obtained with two methods.

pressure levels^{20,21} and possible peripheral vascular diseases of large arteries and not small arteries.²² However, the Arteriograph is certainly much simpler to use compared to the SphygmoCor system since the Arteriograph only measures at one location (the upper arm). Measurement can be done significantly faster.

Conclusion

Our results suggest, that the two methods cannot be used interchangeably either for measuring PWV or for determining Alx. PWV measured with Arteriograph is higher than PWV measured by SphygmoCor system. Working principle of the Arteriograph leads us to the possible conclusion that parameter provided by the Arteriograph is a measure of brachial stiffness and not aortic stiffness. The method used by the Arteriograph is definitely much simpler and more time-efficient than applanation tonometry used by the SphygmoCor device. Probably, however, adjustment of the algorithms could bring the oscillometric method closer to applanation tonometry, which remains for the present the reference method.

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