CARDIO-ANKLE VASCULAR INDEX, AORTIC COMPLIANCE, AND PRESSURE WAVE VELOCITY AS MEASURES OF ARTERIAL STIFFNESS

FIŠER B., SIEGELOVÁ J., DOBŠÁK P., DUŠEK J.

Department of Physiology, Department of Physiotherapy and Rehabilitation,
Department of Functional Diagnostics and Rehabilitation, Faculty of Medicine, Masaryk University,
St. Anne's Faculty Hospital, Brno, Czech Republic

Received after revision Juny 2008

A b s t r a c t

Stiffness of large arteries has been related to cardiovascular mortality. It can be expressed by pressure wave velocity (PWV), aortic compliance (C), and by the cardio-ankle vascular index (CAVI). C was measured non-invasively in normotensive and hypertensive human subjects and in human cadavers' aortas, PWV and CAVI were calculated. Despite completely different experimental situation the results of both analyses were similar. Also, regression coefficients between C and blood pressure were similar in both experimental conditions.

INTRODUCTION

Stiffness of large arteries has been related to cardiovascular mortality (*1*). Methods used to estimate this stiffness include cardiac ultrasound and pulse wave velocity (PWV) (*2*). Arterial stiffness can be expressed by various indexes. Except PWV it is aortic compliance and the cardio-ankle vascular index (CAVI) (*3*). The relationship between these indexes is determined by mathematical equations.

The aim of the present paper was to calculate PWV and CAVI in a group of normotensive and hypertensive subjects where the aortic compliance was non-invasively measured and to compare the results with published data obtained from isolated aortas of human cadavers.

METHODS

The stiffness parameter beta is reported to be independent of blood pressure and is calculated as:

BETA = ln(Ps/Pd)*D/dD...(1)

where Ps and Pd are respectively the systolic and diastolic blood pressures in mmHg. D is the diameter of the blood vessel and dD is the change of D. D/dD can be replaced by 2*V/dV, where V is the volume of the tube, in our case the volume of the aorta.

BETA = ln(Ps/Pd)*2*V/dV..(2)

The relationship between the volume elastic modulus V*dP/dV (index of the stiffness) and PWV is expressed by the formula

$PWV^2 = (V*dP/dV)/\rho$ ....(3)

where ρ is blood density. Aortic compliance is dV/dP. Thus

$V/dV= \rho *PWV^2/dP$..........(4)

If we substitute equation (4) for equation (2), we obtain the stiffness parameter

$BETA = CAVI = \ln(Ps/Pd)*2*(\rho/dP)*PWV^2$..........(5)

and volume measurement by ultrasound is superfluous. The last equation expresses the relationship between CAVI and PWV. On the other hand, direct comparison of these parameters with compliance (dV/dP) is not possible because the value V (aortic volume) is missing. The estimates of V from cadaver studies were used in our comparison.

The cadaver study includes 27 aortas from subjects 20 to 83 years old. The results after (*4*) are published in the Kenner-Wetterer monograph (*5*).

The compliance data were obtained by non-invasive measurement from 8 healthy men 27±9 years old (from 21 to 49 years) with 24-hour blood pressure 121±10 / 75±8 mmHg, from 10 non-treated hypertensive men 48±8 years old (from 38 to 58 years) with 24-hour blood pressure values 147±12 / 88±9 mmHg, and from 6 hypertensive patients treated with verapamil (slow release formula) 240 mg/24 h for 3 months. The mean age was 43±9 years (from 32 to 53). Twenty-four-hour blood pressure values were 143±7 / 88±4 mmHg before the treatment and 131±4 / 80±4 mmHg at the time of compliance investigation. The method and the results of the compliance measurement are described elsewhere (*5*).

RESULTS

The results of the cadaver study are seen in *Fig.1.* From *Fig. 1* it is clear that the slopes of the curves (which correspond to the compliance dV/dP) are pressure-dependent. The parameters of the best fitted polynomal curves are seen in *Table 1,* together with compliance values at 80 mmHg (value of diastolic pressure), the parameters of linear relationship between compliance and pressure, and the calculated PWV at 90 mmHg (value of mean arterial pressure) and CAVI (which is not pressure-dependent). PWV was calculated according to equation (*3*). Because PWV is the aortic pulse-wave velocity, which is different from the cardio-ankle pulse wave velocity, we calculated at first aortic beta according to equation (5), and then we calculated CAVI using the regression equation CAVI = 7.5 + 0.15*aortic BETA (*3*). For CAVI we assume Ps/Pd = 120/80 mmHg.

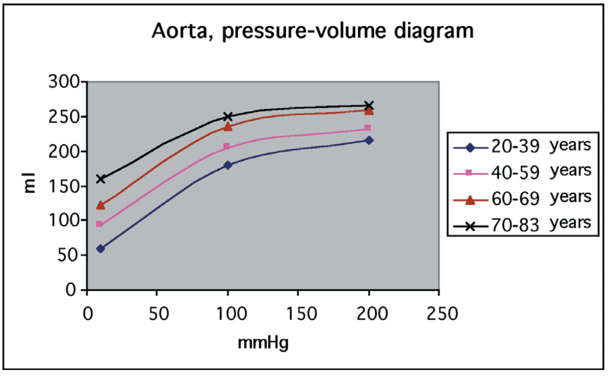

Fig. 1
Pressure-volume diagram of cadavers' aortas

Table 1
Study of cadavers' aortas

Ages (n)	a	b	c	A	B	dV/dp (80 mmHg)	PWV	BETA aortic	CAVI
years						ml/mmHg	m/s		
20–39 (8)	40.54	1.897	-0.0051	1.897	-0.0102	1.081	11.71	21.08	10.66
40–59 (9)	76.77	1.778	-0.0050	1.778	-0.0100	0.978	13.20	26.78	11.51
60–69 (5)	105.10	1.849	-0.0054	1.849	-0.0108	0.985	14.20	31.00	12.15
70–83 (6)	144.40	1.510	-0.0045	1.510	-0.0090	0.790	15.95	39.11	13.36

Legend: parameters a, b, c correspond to equation; volume = a + b* pressure +c* pressure^2; parameters A, B: compliance = A + B* pressure; dV/dP (80 mmHg): compliance at pressure 80 mmHg; PWV: pulse wave velocity; BETA: aortic stiffness; CAVI cardio-ankle vascular index.

The results of the analysis of our compliance data are seen in *Table 2*. The compliance values were non-invasively measured as well as coefficients A and B, which we used for calculation of compliance at 80 mmHg. The volume V was not measured in our study and thus we used the values of V from the studies of cadavers' aortas for the calculation of PWV estimates again for mean pressure of 90 mmHg. The calculation of CAVI was performed identically as in the analysis of cadavers' aortas.

Table 2
Human non-invasive study

Group (n)	dV/dp	A	B	dV/dp (80 mmHg)	PWV	BETA aortic	CAVI
	Ml/mmHg			ml/mmHg	m/s		
Normotensives (6)	1.18 ± 0.25	2.328	0.0154	0.969	11.77	21.29	10.69
Hypertensives (10)	0.96 ± 0.21	2.219	0.0144	0.923	13.37	27.48	11.62
Treated hypertensives (6)	0.90 ± 0.11	1.843	0.0122	0.745	13.86	29.50	11.92

Legend: dV/dp (±SD): measured compliance. Other parameters as in *Table 1*.

Despite a completely different experimental situation the results of both analyses are similar. The most interesting finding is a similar regression coefficient B despite the fact that the smooth muscle cells in cadavers' aortas are dead.

DISCUSSION

Several studies determined the aortic compliance invasively, and the values correspond to our non-invasive methods. Also, the regression coefficient between diastolic pressure and compliance B (0.0157 ml*mmHg^{-2}) is similar in our study and in the study of *Liu et al.* (*14, 15*). They found a value B = 0.0131 ml*mmHg^{-2}. In all compliance studies a big variation of compliance among various subjects was observed.

From this point of view, the accord between the data of cadavers' aortas and those of living subjects is surprising.

A comparison of PWV calculated from our data and PWV measured in healthy subjects revealed that our data correspond to the high 2.5 centile of PWV variation in cadavers' aortas and in our healthy subjects in all age categories. On the other hand, our data from hypertensive and treated hypertensive patients exceed the results of measurement in normotensives. It is interesting that the stiffness is higher in treated hypertensive patients than in non-treated ones. This finding can explain the fact that blood pressure in treated patients was initially higher and blood pressure was relatively quickly normalised by the treatment, while remodelling of the arterial wall needed much more time.

Our analysis indicates that all parameters, aortic compliance, PWV, and CAVI can be used for estimation of arterial stiffness. It seems that the stiffness data are more reliable for determination of patient prognosis without treatment than blood pressure measurement. For screening, the method must be simple to perform. Here is the advantage of the CAVI measurement. CAVI is only age-dependent. PWV is both pressure- and age-dependent. However, CAVI and aortic compliance measurement are not equal. CAVI takes into account the atherosclerosis of arteries of the lower extremities. Thus aortic compliance and CAVI measurement are complementary. Aortic compliance is both pressure- and age-dependent but can be relatively simply normalised for the distinct value of diastolic pressure. The complicated methodical approach causes a limitation of the aortic compliance method for screening purposes.

Acknowledgement

Supported by MSM0021622402.

REFERENCES

1. *Boutouyrie P, Tropeano AI, Asmar R et al.* Aortic stiffness is an independent predictor of primary coronary events in hypertensive patients: A longitudinal study. Hypertension 2002; 39: 10–15.
2. *Baoying LI, Haiqing GAO, Xiaoli LI et al.* Correlation between brachial-ankle pulse wave velocity and arterial compliance and cardiovascular risk factors in elderly patients with arteriosclerosis. Hypertens Res 2006; 29: 309–314.
3. *Takaki A, Ogawa H, Wakeyama T et al.* Cardio-ankle vascular index is a new noninvasive parameter of arterial stiffness. Circ J 2007; 71: 1710–1714.
4. *Yambe T, Yoshizawa M, Saijo Y et al.* Brachio-ankle pulse wave velocity and cardio-ankle vascular index (CAVI). Biomedicine and Pharmacotherapy 2004; 58: 95–98.
5. *Shirai K, Utino J, Otsuka K et al.* A novel blood pressure-independent arterial wall stiffness parameter: cardio-ankle vascular index (CAVI). J Atheroscler Thromb 2006; 13: 101–107.

6. *Khoshdel AR, Thakkinstioan A, Carney SL et al.* Estimation of an age-specific reference interval for pulse wave velocity: a meta analysis. J Hypertension 2006; 24: 1231–1237.
7. *Mizuguchi Y, Oishi Y, Tanaka H et al.* Arterial stiffness is associated with left ventricular diastolic function in patients with cardiovascular risk factors: early detection with the use of cardio-ankle vascular index and ultrasonic strain imaging. J Cardiac Fail 2007; 13: 744–751.
8. *Nakamura K, Tomaru T, Yamamura S et al.* Cardio-ankle vascular index is a candidate predictor of coronary atherosclerosis. Circ J 2008; 72: 598–604.
9. *Simon E, Meyer WW.* Das Volumen, die Volumendehnbarkeit und die Druck-Langen-Beziehungen des gesamten aortalen Windkessels in Abhängigkeit von Alter, Hochdruck und Arteriosklerose. Klein Wschr 1958: 36: 424–432.
10. *Wetterer E, Kenner Th.* Grundlagen der Dynamik des Arterienpulses. Berlin: Springer-Verlag, 1968: 375 pp.
11. *Savin E, Siegelova J, Fiser B et al.* Détermination noninvasive de la compliance aortique chez l'homme. Arch Physiol Biochem 1996;104: 257–264.
12. *Messerli FH, Frohliche ED, Nutura HO.* Arterial compliance in essential hypertension. J Cardiovasc 1985; 7: 33–35.
13. *Simon AC, Safar MF, Levenson JA et al.* An evaluation of large arteries compliance in man. Am J Physiol 1979; 237: 550–554.
14. *Liu Z, Brin KP, Yin FCP.* Estimation of total arterial compliance: an improved method and evaluation of current methods. Am J Physiol 1986; 251: 588–600.
15. *Liu Z, Ting CT, Zhu S, Yin FCP.* Aortic compliance in human hypertension. Hypertension 1989; 14: 129–136.