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Aortic and arterial pulse wave velocity in patients with coronary heart disease of different severity

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Abstract. The objective of the present study was to compare aortic and arterial pulse wave velocity (PWV) in coronary heart disease (CHD) patients and healthy young volunteers. Signals were obtained from 28 subjects. Severe coronary heart disease was confirmed by coronary angiography. Aortic PWV was measured using the TENSIOMed Arteriograph. Four arterial PWVs were gathered using a PowerLab 4/20T. The major finding of this study was that patients with CHD had increased aortic PWV compared with healthy subjects ($P < 0.01$). It was also found that in the CHD group, aortic PWV had a positive correlation with arterial PWV_2, PWV_3 and PWV_4 ($P < 0.01$). Our study showed that difference in aortic and arterial PWV between CHD patients with different atherosclerosis grade was not significant. Further PWV studies should be focused on patients with pronounced risk factors but without established cardiovascular disease that allow to select patients with early phase of atherosclerosis.

Key words: atherosclerosis, coronary heart disease, pulse wave velocity, aortic stiffness, risk factors.

1. INTRODUCTION

Several studies conducted on various groups of the population have shown significant correlations or powerful interactions between PWV (and other parameters concerning arterial wall properties) and the so-called “major” cardiovascular risk factors, such as hypertension, high cholesterol level, diabetes and smoking.

Endothelium modulates arterial stiffness, which precedes overt atherosclerosis and is an independent predictor of cardiovascular events. Dysfunction of the endothelium may be considered an early and potentially reversible step in the process of atherogenesis. Numerous methods have been developed to assess endothelial status and large artery stiffness, including PWV measurements. PWV increases as arterial stiffness rises [1].

Increased brachial-ankle PWV is associated with impaired endothelial function in patients with coronary heart disease [2].

Aortic PWV is an independent predictor of coronary heart disease and stroke in apparently healthy subjects. Aortic stiffness can lead to low diastolic blood pressure, thereby possibly limiting coronary perfusion. In a recent large population based study, performed among elderly subjects, aortic stiffness was strongly and independently associated with coronary atherosclerosis [3].

Studies, examining the relationship between arterial stiffness and atherosclerosis, have reported conflicting results. Some studies found a relationship between arterial stiffness and atherosclerosis, but others did not. Most of the studies investigated the relationship between arterial stiffness and atherosclerosis in only one vessel [4–7].

The objective of the present study was to compare aortic and arterial PWV in CHD patients and healthy young volunteers.

2. METHODS

2.1. CHD patients and healthy young volunteers

Clinical characteristics of the study patients and healthy young volunteers are summarized in Table 1. In the present study 27 subjects were investigated (13 males, 14 females); their mean age was 59.5 years (range 24–81 years). The group of CHD patients consisted of 17 patients, treated in the Department of Cardiology of the North-Estonian Regional Hospital from January to March

Table 1. Characteristics of the study patients and healthy young volunteers

	CHD patients (n = 17)	Healthy young volunteers (n = 10)	P value
Age	66 (49–81)	27.5 (24–36)	
Men	55%	30%	
Diabetes	47%	–	
Hypertension	76%	–	
Myocardial infarction	70%	–	
Systolic blood pressure (mmHg)	150.0 ± 26.8	122.0 ± 14.8	<0.01*
Diastolic blood pressure (mmHg)	90.5 ± 13.6	70.5 ± 6.9	<0.01*

Data are mean ± SD.

* $P < 0.01$, difference is statistically significant.

2007. CHD was confirmed by coronary angiography. Twelve patients out of 17 had suffered from myocardial infarction. Eight patients had been diagnosed with diabetes and 13 were hypertensive. Systolic (150.0 ± 26.8 mm Hg) and diastolic (90.5 ± 13.6 mm Hg) blood pressure was significantly higher in the CHD patients compared to healthy subjects.

The healthy group consisted of 10 subjects (3 males, 7 females), who were persons without any cardiovascular disease or complication. Their mean age was 27.5 years (in the range 24–36).

2.2. Coronary angiography

Coronary angiography was performed by Siemens digital angiograph for all CHD patients. Severity of coronary artery stenosis was graded from grade 1 (up to 25%) to grade 6 (100%, total occlusion). Atherosclerosis grade (from 1 to 10) was evaluated, based on the number of damaged coronary artery segments and severity of stenosis.

2.3. Aortic and arterial pulse wave velocity

Aortic and four arterial pulse wave velocities were obtained for the CHD and healthy group. Measurements were performed by two devices: the TENSIOMed Arteriograph for aortic PWV and PowerLab 4/20T for arterial pulse wave velocities. Measurements were performed one after another in laboratory conditions in the supine position for about 15 min.

Aortic PWV was measured using the TENSIOMed Arteriograph (TensioMED Ltd., Hungary). The measurement is based on the fact that during systole, the blood volume ejected into the aorta generates a pulse wave (early systolic peak). This pulse wave runs down and reflects off the bifurcation of the aorta, creating a second wave (late systolic peak). The difference between the first and reflected systolic waves (in msec) is related to the stiffness of the aorta. On the basis of this, the characteristic aortic PWV can be calculated. According to the TENSIOMed Arteriograph data, optimal Aortic PWV is less than 7 m/s.

Arterial pulse wave velocities were measured using the PowerLab 4/20T. For piezoelectric signal measurements piezoelectric sensors (MLT 1010 pulse transducer, AD Instruments) were used. During the study, signals were simultaneously acquired from the hand and leg. First, signals from the hand were registered; three major sites were used to attach sensors: fingertip, wrist and elbow. Then sensors were attached to the leg to the toe and popliteal space (Fig. 1). The distance travelled by the pulse wave between the sites was measured over the surface of the body with a tape measure. PWV was calculated as the ratio of the distance travelled by the pulse wave and the foot-to-foot time delay, expressed in m/s. PWV was calculated on the basis of the mean of 10 consecutive pulse waveforms to cover a complete respiratory cycle. The duration of measured signal was 15 min. The process of transition from one pulse to

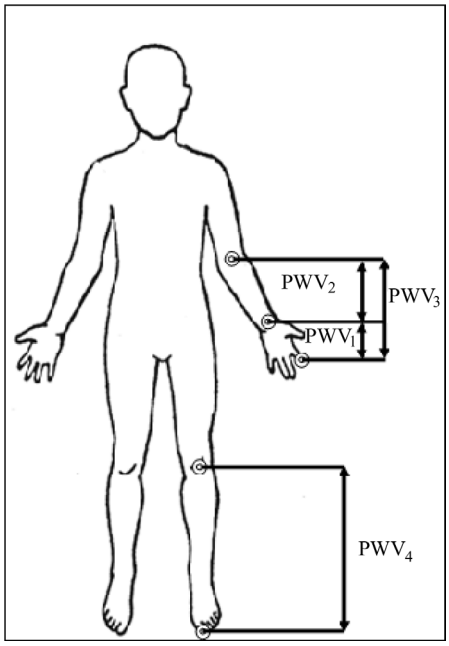

Fig. 1. Arterial pulse wave velocity measurement sites.

another was manual, which allowed editing of any poorly recognized pulse landmarks. The pulses were smoothed using digital low-pass (50 Hz) and high-pass (8 Hz) filters to remove the low frequency baseline. Anomalous pulses due to the patients' movements or irregular breathing were excluded from the analysis. Based on the recorded signals, four pulse wave velocities were calculated: PWV_1, PWV_2, PWV_3 and PWV_4 (Fig. 1). These acronyms will be used hereinafter for the purpose of clarity.

2.4. Statistical analysis

All data analysis was performed using the program SPSS 10.0 for Windows. Data were expressed as the mean ± SD. Multiple linear regression analysis (Pearson correlation) was used for the relationships between risk factors and PWV, and between pulse wave velocities measured in different sites of the arterial tree. The value of $P < 0.05$ was considered statistically significant.

3. RESULTS

The results of the study are summarized in Table 2. Aortic PWV was significantly increased in the CHD group compared with that in the healthy group.

Table 2. Aortic and arterial pulse wave velocities (m/s) in CHD and healthy groups

	CHD patients (n = 17)	Healthy young volunteers (n = 10)	P value
Aortic PWV	10.2 ± 1.8	6.6 ± 0.8	<0.01
PWV_1	6.8 ± 2.0	5.2 ± 1.9	NS
PWV_2	8.1 ± 2.2	7.6 ± 0.8	NS
PWV_3	7.8 ± 1.4	6.4 ± 1.1	NS
PWV_4	7.7 ± 1.0	6.9 ± 0.7	<0.01

Data are mean ± SD, NS – non-significant.

There was no significant difference between pulse wave velocities, obtained from the upper limbs (PWV_1, PWV_2 and PWV_3). PWV obtained from the lower limbs (PWV_4) was significantly increased in the CHD group compared with that of the healthy group (7.7 ± 1.0 vs 6.9 ± 0.7 m/s, $P < 0.01$).

One of the objectives of this study was to find out if there is any correlation between aortic and arterial PWV in CHD and healthy groups. Multiple regression analysis showed that in the CHD group, aortic PWV had a positive correlation with arterial PWV_2, PWV_3 and PWV_4 ($P < 0.01$). The results are shown in Table 3. From these results we can see that strongest correlation exists between aortic PWV and arterial PWV_2.

The correlation data between aortic PWV and arterial pulse wave velocities in the healthy group is shown in Table 4. None of the arterial pulse wave velocities were significantly correlated with aortic PWV.

Table 3. Pearson correlation coefficients between aortic and arterial PWV in CHD patients (n = 17)

	Pearson correlation coefficient	P value
PWV_1	0.072	NS
PWV_2	0.501	<0.01
PWV_3	0.262	<0.01
PWV_4	0.231	<0.01

Table 4. Pearson correlation coefficients between aortic and arterial PWV in the healthy group (n = 10)

	Pearson correlation coefficient	P value
PWV_1	0.123	NS
PWV_2	–0.168	NS
PWV_3	–0.134	NS
PWV_4	–0.293	NS

Table 5. Aortic PWV and arterial PWV_4 (m/s) in CHD patients with different atherosclerosis grades

Atherosclerosis grade	[1–6]	[7–10]	*P* value
Number of patients	7	10	
Aortic PWV	11.08 ± 1.8	9.8 ± 2.0	NS
Arterial PWV_4	7.75 ± 1.0	8.0 ± 1.15	NS

Table 6. Aortic PWV and arterial PWV_4 (m/s) in CHD patients with and without diabetes

	Diabetic patients (n = 8)	Non-diabetic patients (n = 9)	*P* value
Aortic PWV	10.3 ± 2.1	10.06 ± 1.7	NS
Arterial PWV_4	8.57 ± 1.0	7.7 ± 1.15	NS

Table 7. Aortic PWV and arterial PWV_4 (m/s) in CHD patients with and without previous myocardial infarction (MI)

	MI patients (n = 12)	Non-MI patients (n = 5)	*P* value
Aortic PWV	10.17 ± 1.8	9.8 ± 1.9	NS
Arterial PWV_4	8.5 ± 1.0	7.2 ± 0.7	NS

We also studied the difference of aortic and arterial PWV in patients depending on disease severity. As only one arterial PWV (PWV_4) showed significant difference between CHD patients and healthy young volunteers, it was decided to use only PWV_4 in further analysis. Patients were classified into 2 groups: patients with arteriosclerosis grades from 1 to 6 and patients with arteriosclerosis grades from 7 to 10. Neither aortic PWV nor arterial PWV_4 were significantly different between patients with different severity coronary heart disease. The results are shown in Table 5.

Difference of aortic and arterial PWV in patients with and without diabetes was also analysed. No significant difference was found (Table 6).

The difference in aortic and arterial PWV in patients with and without myocardial infarction (MI) was investigated. No significant difference was found (Table 7).

4. DISCUSSION

Because endothelial dysfunction reflects a systemic vascular abnormality, we can indirectly evaluate the endothelial function of the coronary arteries by examining aortic stiffness or elastic properties of arterial arteries.

4.1. Comparison between CHD patients and healthy young volunteers

Some previous studies on the association between arterial stiffness and atherosclerosis have reported contradictory results. Non-invasive measurement of distensibility of the carotid artery has been shown to be closely related to post-mortem established atherosclerosis of the carotid artery [4]. Other studies have found no relationship between arterial stiffness and atherosclerosis. One of the studies has found changes in PWV with age in populations with different prevalence of atherosclerosis and has concluded that arterial distensibility is not associated with atherosclerosis [5]. The paper [6] examines the relationship between distensibility and intima-media thickness of the common carotid artery. No association between arterial wall thickness and increased arterial stiffness was observed, except for the thickest 10% of the artery walls.

In [7] a significant increase in the PWV was found in diabetic subjects. The high values of PWV were indicative of an incipient process of diffuse atherosclerosis, and measurement of the PWV brought this into evidence earlier than the classic signs and symptoms.

The major finding of the present study is that patients with CHD have increased aortic PWVs compared with healthy subjects. This demonstrates that patients with CHD have impaired endothelial function compared with healthy subjects that is consistent with a previous publication [3]. The results of the present study also show that only one of the arterial pulse wave velocities (PWV_4) was significantly increased in the CHD group. This can be explained by the fact that the atherosclerosis is much more pronounced in lower limb arteries.

An apparent, although not significant difference was also found between arterial pulse wave velocities obtained from upper limbs (PWV_1, PWV_2 and PWV_3) in patients with CHD and in the healthy group. This finding indicates that atherosclerotic changes of the wall of the upper limb arteries are less pronounced as atherogenesis in upper limb arteries is retarded compared to lower limb arteries. However, to obtain a significant difference between groups, a higher number of patients should be investigated.

The strong association of aortic stiffness with atherosclerosis at various sites of the arterial tree suggests that aortic stiffness can be used as an indicator of the generalized atherosclerosis [8]. The findings of our study confirm almost the same as aortic stiffness is associated with the increase of PWV.

PWV has been also found to increase with aging [9–11]. In our study, the healthy group was significantly younger than the patients. Increase in PWV in the CHD patients group was to be expected since the arteries become less distensible due to structural changes that take place with age.

4.2. Comparison of CHD patients with different severity

Our study showed that the difference in aortic and arterial PWV between CHD patients with different atherosclerosis grade was not significant. There was

also no difference between diabetic and non-diabetic patients and between patients with or without previous myocardial infarction. This can be explained by the fact that in patients atherosclerosis was advanced and atherosclerotic changes were already present in all patients.

Previous studies with intravascular ultrasound (IVUS) have revealed that the atherosclerotic process starts first in the arterial wall. This disease is primarily not a disease of the lumen, but a disease of the vessel wall. It is the atheroma in the vessel wall that determines the natural history and pathophysiology of the disease. A vessel that appears completely normal (i.e., no luminal narrowing) in angiography is often found to be burdened with atheroma in IVUS imaging. IVUS can image lesion characteristics more reliably than angiography and has shown that atherosclerotic burden begins in life earlier than expected [12]. This shows that formation of atherosclerotic plaques takes place in later stages. Patients for our study were chosen on the basis of the angiography investigation; hence they were in late stages of atherosclerosis. The recent 2007 European Guidelines for the Management of Arterial Hypertension for the first time advised the use of PWV measurement for the assessment of cardiovascular risk and subclinical organ damage. The European SCORE-chart is widely used for estimating the cardiovascular risk [13]. Individuals with a 10-year risk of fatal cardiovascular disease higher than 5% belong to the high-risk group.

IVUS is an expensive and complicated technology. Thus the non-invasive simple PWV analysis method is needed to be able to select patients with the early phase of atherosclerosis. Further PWV studies should be focused on patients with pronounced risk factors but without established cardiovascular disease.

5. CONCLUSIONS

The major finding of this study was that patients with CHD had increased aortic PWV compared with healthy subjects. It was also found that in the CHD group, aortic PWV had a positive correlation with arterial PWV_2, PWV_3 and PWV_4 ($P < 0.01$). Our study showed that difference in aortic and arterial PWV between CHD patients with different atherosclerosis grades was not significant. Neither was there a difference between diabetic and non-diabetic patients and in groups with or without previous myocardial infarction. Although limitation of this study might be the use of healthy young volunteers. Further PWV studies should be focused on patients with pronounced risk factors but without established cardiovascular disease, which would allow us to select patients with early phase of atherosclerosis.

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Aordi ja arteriaalne pulsilaine kiirus erineva raskusastmega südame isheemiatõve haigetel

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Aordi pulsilaine leviku kiirus (PLK) prognoosib suremust südame-veresoonkonnahaigustesse, südame isheemiatõbe ja infarkti. Nende haiguste põhjustajaks on ateroskleroos ehk arterite lubjastus. PLK sõltub arterite seina venitatavusest, veresoone seina paksusest ja veresoone raadiuse suurusest. Normaalselt on veresoone sein elastne. Ateroskleroosi puhul veresoonte seinad jäigastuvad ja PLK suureneb. Seega võib PLK mõõtmist kasutada kui mitteinvasiivset meetodit ateroskleroosi hindamiseks. Käesoleva uuringu eesmärk on võrrelda aordi ja arterite PLK-d tõsise koronaararterihaigusega patsientide ning tervete inimeste vahel. Pulsilaine signaalide mõõtmised on teostatud 28 uurimisalusel patsiendil. Aordi PLK on mõõdetud TENSIOMedi seadmega ja arterite PLK mõõtmist on teostatud PowerLab 4/20T seadet kasutades. Töö käigus on leitud, et südame isheemiatõve patsientide aordi PLK on kiirenenud, võrreldes tervete isikutega. Samuti korreleerub nende aordi PLK positiivselt arteriaalse PLK-ga. PLK statis-

tiliselt olulist erinevust erineva raskusastmega koronaaraterosklerоosiga südame isheemiatõve haigete gruppide vahel ei leitud. Edaspidi on vaja teha täiendavaid uuringuid ja analüüsida isikuid, kellel esinevad südamehaiguste riskifaktorid, kuid kellel pole veel südame-veresoonkonnahaigusi, mis võimaldaks neil ateroskleroosi varasemas faasis välja selgitada.