Changes of Pulse Wave Velocity in the Lower Limbs in Hypertensive Patients

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Abstract

Increased arterial stiffness is connected with vascular aging and cardiovascular diseases. Arterial stiffness correlates to Pulse Wave Velocity (PWV) which can be measured by the bioimpedance method.

The bioimpedance plethysmographic signal was measured by a non-invasive Multichannel Bioimpedance Monitor and the PWV in the thigh and calf was calculated. Protocol: 2-minutes in the horizontal position, 5-minutes head-up tilt test (70°). Subjects: 25 healthy (14 women and 11 men) non-smoking volunteers and 24 patients treated for hypertension (12 women and 12 men).

The PWV values during different positions for the right and left leg of the subject were evaluated and averaged. The relative $PWVr=PWV_{tilt} / PWV_{horizontal}$ *was calculated. The unpaired t-test to evaluate the significance of differences between groups was used. There were no significant differences in the basic parameters (age, height, weight) of the healthy group versus the patient group. The significant difference was in the PWVr parameter (*$p<0.05$*): 1.27±0.17 for the healthy group and 1.17±0.15 for the patient group.*

A decrease in the PWVr in the patient group treated for hypertension was statistically significant in comparison with the healthy group with similar values of blood pressure, weight and height. This result reflects the different reaction of the vascular system to the tilt test in the patient group.

1. Introduction

Hypertension is considered to be one of the main risk factors regarding cardiovascular diseases, particularly cerebral stroke and myocardial infraction [1].

Improving knowledge about the vascular condition and the differences of the pulse wave velocity of patients who have suffered various illnesses could lead to a better understanding of pathological changes in the vascular tree. It may well be the way forward regarding more accurate diagnostics and monitoring of the development of illnesses.

Measurement of the PWV is the simple way to measure the stiffness of a specific arterial segment, as it is non-invasive, reproducible, and supported by considerable scientific literature [1].

The PWV reference values during the Valsalva and Mueller manoeuvres in young healthy adults were presented in a previous study [2].

The aim of this study was to compare the PWV values in the lower limbs of normotensive volunteers and hypertensive patients with a similar age and gender distribution.

2. Methods

2.1 Subjects

Two subject groups were established: the patient group consisted of 24 subjects (12 women, 12 men) treated for hypertension and the healthy group consisted of 25 healthy non-smoking volunteers (14 women, 11 men). A description of the healthy group and the patient group is shown in Table 1.

Table 1. Description of the subjects. HG - healthy group, PG - patient group, SD - standard deviation, Q1 - lower quartile, Q3 - upper quartile, NS - non-significant result of t-test.

		Age	Height	Arm span	Weight
		[years]	[m]	[m]	[kg]
Mean	HG	58.0	1.71	1.74	75.5
	PG	63.0	1.69	1.73	81.8
SD	HG	9.8	0.10	0.13	13.8
	PG	13.8	0.11	0.11	19.0
Q1	HG	53.0	1.63	1.64	64.0
	PG	57.0	1.63	1.67	69.6
Q3	HG	64.0	1.77	1.86	85.5
	PG	71.5	1.76	1.79	91.5
p-value		NS (0.1535)	NS (0.5109)	NS (0.7661)	NS (0.1866)

2.2 Study protocol

The study protocol consisted of 120 seconds in a horizontal (supine) position, followed by 300 seconds of the head-up tilt test (70°) and 720 seconds back in the horizontal position.

Measurements were performed by a Multichannel Bioimpedance Monitor (MBM), the device developed by the Institute of Scientific Instruments of The Czech Academy of Sciences [3].

Impedance signals were measured between surface electrodes on the thigh and the calf as shown in Figure 1 and Figure 2 - Z_{thigh} and Z_{calf}.

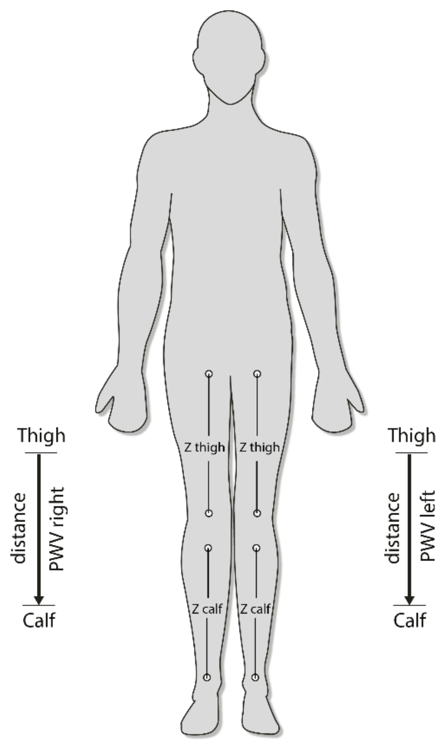

Figure 1. Placement of impedance electrodes and investigated PWVs [4].

PWV beat-to-beat values were computed [5] as:

$$PWV = \frac{distance}{time\ delay}\left[\frac{m}{s}\right]. \qquad (1)$$

The distance in a direct line between the thigh and the calf for each patient was taken (Figure 1).

Signal processing was conducted as follow: the maximum of the negative impedance derivative (*–dZ/dt*) was detected (Figure 3 – black points) and the time delay between the R wave and the detected maxima of the negative impedance derivative for each beat was calculated.

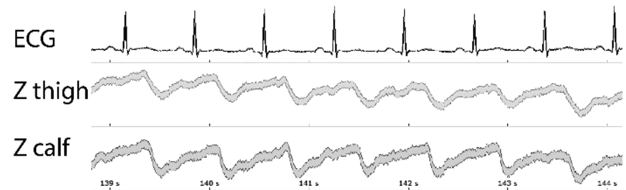

Figure 2. Example of measured signals in the horizontal position of the left leg. *ECG* (top) and impedance signals $Z_{thigh\ left}$ (middle), $Z_{calf\ left}$ (bottom).

As shown in Figure 3 the time delay t_{thigh} and t_{calf} is the time delay between the R wave and these maxima (black points) for each RR interval.

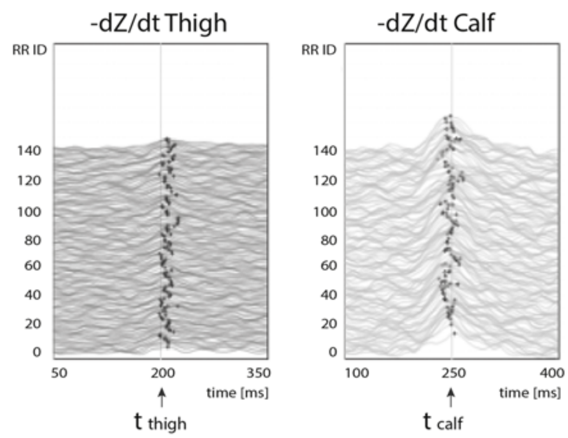

Figure 3. Example of derivative impedance signal (thigh, calf, horizontal position) beat-to-beat processed by the PulsWave software. X-axes represent the time delay from the R wave. Y-axes represent heart beat index (RR ID). The maxima of the negative impedance derivative are presented by black points.

The time delay in Equation 1 between t_{thigh} and t_{calf} (Figure 3) was calculated as:

$$time\ delay = t_{calf} - t_{thigh.} \qquad (2)$$

The PWV values were calculated by using PulsWave software version 1.1.0.0 (part of the MBM device), using 60 seconds interval in the horizontal position and the last 60 seconds interval of the tilt test.

2.4 Statistical Analysis

Averaged values of the PWV in the lower limbs (from the right and left side) for each subject during the tilt test (*PWVtilt*) and the horizontal position (*PWVhorizontal*) were computed.

Subsequently, the PWV relative values (*PWVr*) for each subject group were calculated as follows:

$$PWVr = \frac{PWV_{tilt}}{PWV_{horizontal}}. \quad (3)$$

An unpaired t-test to test the statistical difference between healthy subjects and patients was used.

The mean arterial pulse and pulse pressure for each subject was calculated [1] as follow:

$$MAP = \frac{2*DBP+SBP}{3} \quad (4)$$

and

$$PP = SBP - DBP, \quad (5)$$

where *MAP* is mean arterial pulse, *PP* is pulse pressure, *DBP* is diastolic blood pressure and *SBP* is systolic blood pressure.

3. Results

Statistical difference between age, height, arm span and weight of the patient group and the healthy group, was tested by a t-test. There was no statistically significant difference.

The blood pressure values measured in a horizontal position are presented in Figure 4.

Statistical difference between the blood pressure of the patient group and the healthy group, was tested by a t-test. There was no statistically significant difference.

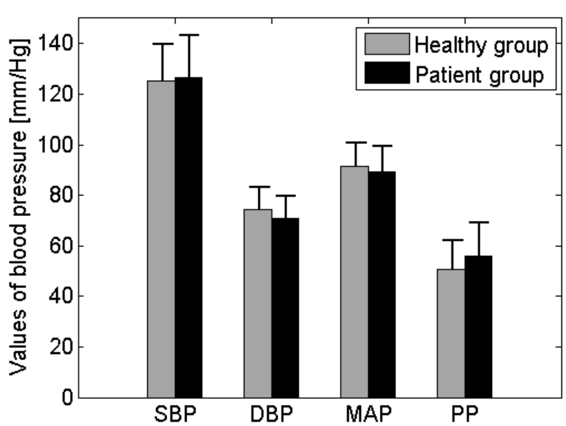

Figure 4. Values of blood pressure whilst in a horizontal position in the healthy group and the patient group. SBP (systolic blood pressure), DBP (diastolic blood pressure), MAP (mean arterial pressure); PP (pulse pressure). The Y-axis represents mean ± standard deviation.

Figure 5 represents the decreasing impedance in the thigh (Z_{thigh}) and the calf (Z_{calf}) when the subject was exposed to the tilt test.

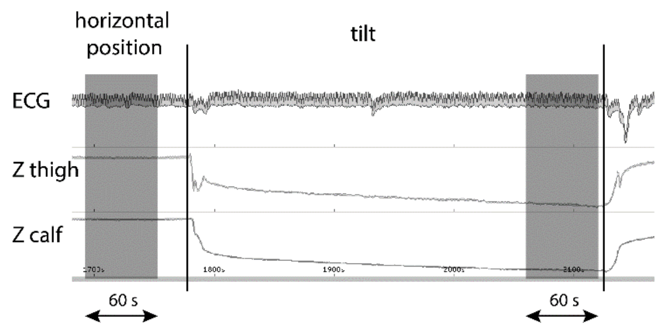

Figure 5. Change of ECG and the decreasing impedance Z_{thigh} , Z_{calf} during the tilt test, left leg.

Table 2 and Table 3 show the values of the PWV calculated for the left and the right leg.

Table 2. Values of the PWV (mean ± standard deviation), horizontal position.

Horizontal position PWV values [m/s]	Healthy group	Patient group
Left leg	11.7±1.8	11.9±1.5
Right leg	11.7±1.8	11.7±1.6

Table 3. Values of the PWV (mean ± standard deviation) during the tilt.

Tilt test PWV values [m/s]	Healthy group	Patient group
Left leg	14.5±1.8	13.7±1.9
Right leg	14.8±2.0	13.8±2.1

Averaged PWV values whilst in the horizontal position and during the tilt test are presented in Table 4.

Table 4. Averaged values (mean ± standard deviation) of the PWVs in the lower limbs whilst in the horizontal position and during the tilt test in the healthy group and the patient group. HG - healthy group, PG - patient group, SD - standard deviation, NS - non-significant result of t-test.

PWV values [m/s]	Mean	SD	p-value
	HG/PG	HG/PG	
Horizontal position	11.6/11.8	1.7/1.4	NS(0.6512)
Tilt test	14.6/13.7	1.9/1.7	NS(0.0946)

There was no statistically significant difference between the horizontal position and the tilt test.

The t-test indicated statistically significant differences in relative changes of the PWV values (PWVr) between the healthy group and the patient group ($p = 0.0361$) as shown in Figure 6.

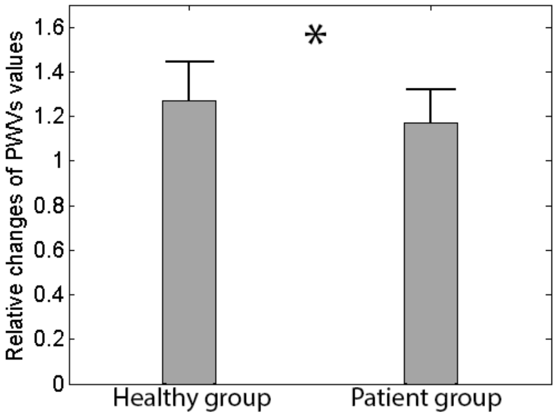

Figure 6. Relative changes in the PWV values (PWVr) tilt test versus horizontal position calculated by Equation (3), mean ± standard deviation, t-test healthy group versus patient group * $p<0.05$.

4. Discussion

Two study groups were established. There was a group of healthy subjects and a group of patients treated for hypertension.

Both investigated subject groups were of similar age, height, weight and gender distribution.

Impedance signals in the lower limbs and ECG for each subject were measured and the PWV values were calculated.

Average PWV values from both legs were computed and the relative changes (PWVr) during the horizontal position and tilt test were calculated.

As shown in Table 2, Table 3 and Table 4 the PWV increased during the tilt test without a statistically significant difference between the healthy group and the patient group.

Values of blood pressure were without a statistically significant difference (Figure 4).

Although absolute values of the PWV in the lower limbs whilst in the horizontal position and during the tilt test were without a statistically significant difference between the healthy group and the patient group (Table 4), Figure 6 shows a statistically significant difference between these groups in the relative changes of the PWV calculated for tilt and horizontal values. It could reflect a lower reaction of the vascular system during exposure to the tilt test in the patient group.

These results could lead to discussions about the successful treatment and the influence of hypertension treatment regarding the variability of the PWV.

5. Conclusion

Normal and hypertensive groups were compared, showing no significant difference in the PWV whilst in the horizontal position and during the tilt test but showing a significant decrease of the PWVr in the patient group.

Computation of the PWVr shows a higher relaxation of the vascular system in patient group during the tilt test. This may be caused by medication.

Acknowledgments

Supported by the European Regional Development Fund the FNUSA-ICRC project (No. CZ.1.05/1.1.00/02.0123) and the PRECEDENCE project (No CZ.1.05/3.1.00/13.0292).

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