Measurement of Pulse Wave Velocity during Valsalva and Mueller Maneuvers by Whole Body Impedance Monitor

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Abstract

Elevated arterial stiffness is a marker of vascular aging and is connected with increased mortality. Noninvasive measurement of arterial stiffness is based on the measurement of pulse wave velocity (PWV), where PWV correlates with arterial stiffness. PWV depends on blood pressure and other physiological conditions.

The aim of our study was to measure and analyze the effect of changes in airway pressure to PWVs between the chest and limbs. Valsalva and Mueller maneuvers and spontaneous breathing were used. We measured 30 healthy, non-smoking subjects aged between 21 and 35 years. Simultaneous measurements of whole body impedance, blood pressure and ECG were taken in a supine position. The relative changes in PWV values (mean ± standard deviation) during the Valsalva maneuver were: 0.82 ± 0.11 (thigh); 0.87 ± 0.10 (calf); 0.64 ± 0.19 (arm); 0.75 ± 0.16 (forearm); during the Mueller maneuver they were: 0.92 ± 0.11 (thigh); 0.91 ± 0.09 (calf); 0.76 ± 0.19 (arm); 0.81 ± 0.14 (forearm). PWVs were lower during maneuvers than during spontaneous breathing. Changes in PWV during breathing maneuvers were more reflected nearer to the chest.

Our results show PWV reference values between various parts of the human body during changes in airway pressure demonstrated by the Valsalva and Mueller maneuvers.

1. Introduction

Cardiovascular disease is the leading cause of mortality in most industrialised populations [1]. PWV is one of the possible evaluable parameters for assessing the state of the arterial tree.

Measurement of PWV is the simplest way to measure the stiffness of a specific arterial segment, as it is non-invasive, reproducible, and supported by considerable scientific literature [2].

PWV values (from the aortic arch to the popliteal artery) for adults were presented (Koivistoinen et al. 2007) for a healthy Finnish population during spontaneous breathing (SB). These PWV values were computed for males and females aged between 26 and 41 years [3].

The aim of our study was to define PWV reference values for young, healthy adults during Valsalva and Mueller maneuvers for various parts of the body.

PWV values calculated for the chest and calf during SB were compared by Koivistoinen et al [3].

2. Methods

In our presented study, PWVs were measured during SB and breathing maneuvers. The Valsalva maneuver consisted of 15 seconds of forced expiration through a closed mouthpiece connected to pressure indicator [4]. During the Valsalva maneuver airway pressure increased (+50cm H_2O). The Mueller maneuver consisted of 15 seconds of forced inspiration through a closed mouthpiece. Airway pressure decreased (-50cm H_2O) during the Mueller maneuver.

SB at the beginning and between maneuvers lasted 120 seconds. PWVs were measured between various parts of the body simultaneously.

Measurements were performed by Multichannel bioimpedance monitor (MBM). Continuous blood pressure (BP), electrocardiography (ECG) and phonocardiography (PCG) were measured with impedance signals (Z) simultaneously.

A pressure indicator was part of the measurement apparatus and was instrumental in providing feedback about the subjects' airway pressure during breathing maneuvers.

2.1. Study protocol

The study protocol consisted of 120 seconds of SB, 15-second Valsalva maneuver, 120 seconds of SB, 15-

second Valsalva maneuver, 120 seconds of SB, 15-second Mueller maneuver, 120 seconds of SB and 15-second Mueller maneuver, performed in a supine position. The first SB was used for statistical significance testing.

2.3. Subjects

The statistical group consisted of 30 healthy, non-smoking volunteers: 14 men and 16 women aged between 21 and 35 years. Table 1 shows a description of this statistical group.

Table 1. Description of the statistical group.

	Minimum	Maximum	Median
Age	21	35	23
Height [m]	1.5	1.9	1.7
Arm span [m]	1.6	2.0	1.8
Weight [kg]	42.0	103.0	73.0
BMI [kg/m^2]	14.9	29.1	22.5

2.4. Signals and data analysis

The multichannel bioimpedance monitor measured 18 channel impedance signals (Z). The chest and limb impedance signals were chosen for data analysis (Figure 1).

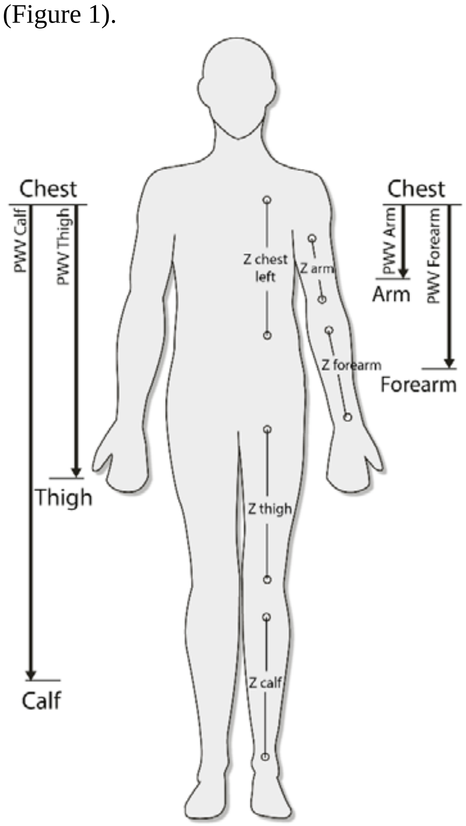

Figure 1. Schematic placement of chosen impedance electrodes and four investigated PWV [5].

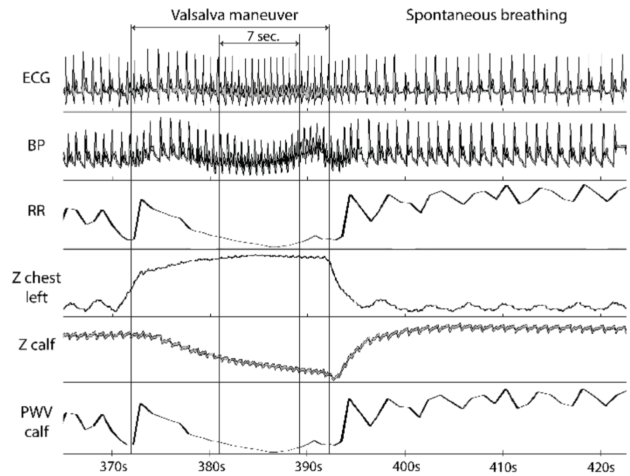

Figure 2. Example of signals during the Valsalva maneuver. ECG electrocardiogram, BP blood pressure, RR time interval between two R waves, Z impedance, and PWV pulse wave velocity.

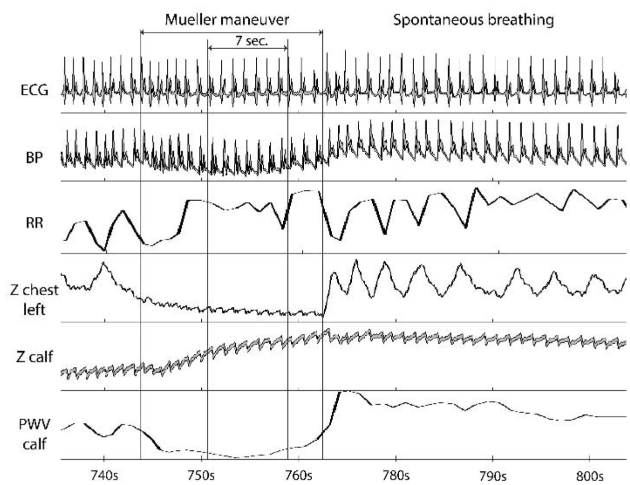

Figure 3. Example of signals during the Mueller maneuver. ECG electrocardiogram, BP blood pressure, Z impedance, and PWV pulse wave velocity.

Figure 2 and Figure 3 show examples of the measured and computed signals during SB and the Valsalva and Mueller maneuvers. The maxima of the negative impedance derivative were calculated from Z impedance signals measured. Beat-to-beat PWV values were computed as follows:

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

where distance was measured between the chest and limbs for each subject, and time delay was the time delay of the maxima of the negative limb impedance signal and chest impedance signal derivative (Figure 4).

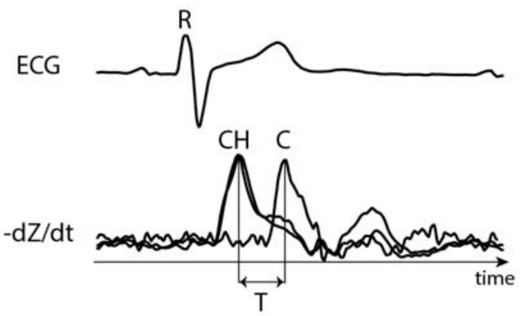

Figure 4. Schematic demonstration of time delay calculated. CH average of the maximum of the negative chest (left) impedance derivative and the maximum of the negative chest (right) impedance derivative, C maximum of the negative calf impedance derivative, R R-wave, T time delay between CH and C.

2.5. Statistical analysis

PWV values for statistical analysis during the Valsalva and Mueller maneuvers were computed as the median values of a 7-second block in the middle of the corresponding maneuver. PWVs for SB were calculated as the median value of a 61-second block in the middle of the SB (at the beginning of the measurement).

The null hypotheses were tested by the Sign test. Correlation between PWV and BP was tested.

3. Results

PWV values during SB and the Valsalva and Mueller maneuvers are presented in Table 2.

Table 2. Reference values (mean ± standard deviation) of PWVs during SB, Valsalva and Mueller maneuvers between the chest and limbs for young healthy adults.

PWV [m/s]	SB	Valsalva	Mueller
thigh	5.6 ± 0.7	4.6 ± 0.7	5.2 ± 0.8
calf	6.7 ± 0.7	5.8 ± 0.7	6.1 ± 0.8
arm	12.8 ± 3.2	7.9 ± 1.9	9.5 ± 3.0
forearm	11.9 ± 2.4	8.7 ± 1.7	9.4 ± 1.7

Null hypothesis H0: No difference in PWV between repeated maneuvers, was not rejected. Therefore PWV values during breathing maneuvers were used from the first Valsalva and Mueller maneuvers.

Statistically significant differences between SB and the Valsalva maneuver (H02: No difference in PWV during SB and the Valsalva maneuver) were concluded in all cases ($p<0.001$).

Statistically significant differences between SB and Mueller maneuver (H03: No difference in PWV during SB and the Mueller maneuver) were concluded in all cases ($p<0.001$).

Null hypothesis H04: No difference in relative PWV changes (breathing maneuver versus SB) during the Valsalva and Mueller maneuvers were not rejected for calf and forearm measurements. Statistically significant differences were concluded in other cases (thigh $p = 0.0019$, arm $p = 0.0176$).

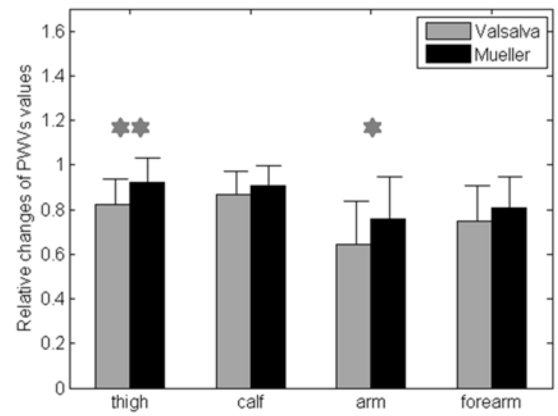

Figure 5. Relative changes in PWV values (breathing maneuvers versus SB), mean ± standard deviation, Sign test Valsalva versus Mueller * $p<0.05$, ** $p<0.01$.

The sign test indicated statistically significant differences of diastolic and pulse pressure during different breathing maneuvers (Valsalva versus Mueller $p < 0.001$).

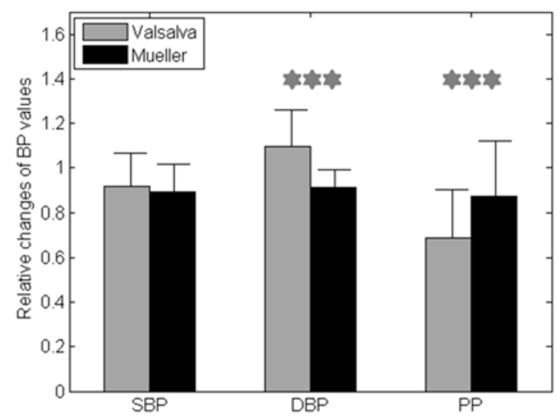

Figure 6. Relative changes in BP values (breathing maneuvers versus SB), mean ± standard deviation, Sign test Valsalva versus Mueller *** $p<0.001$, SBP systolic BP, DBP diastolic BP, and PP pulse pressure.

Changes in PWV corresponded with systolic BP which decreased during both maneuvers. Diastolic BP during the Valsalva maneuver increased and during the Muller maneuver it decreased. Small differences in PWV during the maneuvers corresponded with the differences in pulse BP during maneuvers (Figure 6).

Table 3 shows the relation between relative changes in

PWV and BP. The maximum correlation during the Valsalva maneuver was between systolic BP and calf PWV. The maxima of correlation during the Mueller maneuver were between diastolic BP and thigh and calf PWV.

Table 3. Correlation of relative changes in PWV and BP during breathing maneuvers. V Valsalva, M Mueller, SBP systolic BP, and DBP diastolic BP.

	V SBP	V DBP	M SBP	M DBP
thigh	0,49	0,36	0,21	0,54
calf	0,57	0,44	0,23	0,54
arm	0,37	0,29	0,37	0,24
forearm	0,46	0,35	0,42	0,30

4. Discussion

PWV reference values during breathing maneuvers were established for young, healthy adults (21-35 years). PWVs were lower during maneuvers than during SB (Sign test, $p<0.001$), and during the Valsalva maneuver they were slightly lower than during the Mueller maneuver.

PWV values measured between the aortic arch and the popliteal artery in a healthy population aged between 26 and 41 years (Koivistoinen et al 2007) were computed as 7.7 ± 1.2 for males and 7.0 ± 1.0 for females (PWV±SD) [3]. Our study for a healthy population aged between 21 and 35 years measured PWVs between the chest and calf. Values were 6.7 ± 0.6 for males and 6.8 ± 0.7 for females. The small difference in PWV values between studies could be due to the low age of the population in our study because PWV values are physiologically higher with increasing age. These results confirm the valid PWV values measured during SB.

Figure 5 and Figure 6 show that the Valsalva maneuver had a bigger influence on the hemodynamic system compared to the Mueller maneuver. Relative PWV values decreased more, and relative changes in BP were different during the Valsalva maneuver (systolic pressure decreased, diastolic pressure increased and pulse pressure decreased).

Further changes in PWV during breathing maneuvers were more reflected nearer the chest (PWV thigh and PWV arm) where the decrease in PWV was bigger. This leads to the conclusion that the major component of this change is caused by changes in chest pressure during these maneuvers.

The maximum of PWV and BP correlation was different for each breathing maneuver (Table 3). The maxima of correlation during the Valsalva maneuver were for systolic BP, although the diastolic relative change in BP was slightly greater versus systolic BP. The maxima of correlation during the Mueller maneuver were for diastolic BP, although the systolic relative change in BP was slightly greater versus diastolic BP. These conclusions could be used for further exploration.

5. Conclusion

Evaluation of changes in PWV during various conditions could contribute to diagnosis of cardiovascular disease. In this study, changes in airway pressure were simulated using the Valsalva and Mueller maneuvers.

This study shows PWV reference values between various places on the human body during breathing maneuvers. During the continuation of the study subjects of various age and with various diagnoses will be measured.

Acknowledgments

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References

[1] Asmar R, O'Rourke M. Arterial stiffness and pulse wave velocity: clinical applications. 1st ed. Amsterdam: Elsevier, 1999.

[2] Salvi P. Pulse Waves. Milan: Springer Milan, 2012.

[3] Koivistoinen T, et al. Pulse wave velocity reference values in healthy adults aged 26-75 years. Clinical Physiology and Functional Imaging 2007;27:191-6.

[4] Monge Garcia M.I. et al. Arterial pressure changes during the Valsalva maneuver to predict fluid responsiveness in spontaneously breathing patients. Intensive Care Medicine 2009;35:1:77-84.

[5] Plesinger F. et al. Influence of tilt load on pulse wave velocity in the lower limbs. In: 2014 8th Conference of the European Study Group on Cardiovascular Oscillations (ESGCO). IEEE 2014:77-78.

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