Assessment of Relationships between Blood Pressure, Pulse Wave Velocity and Digital Volume Pulse

JM Padilla[1,2], EJ Berjano[1], J Sáiz[1], L Fácila[3],
P Díaz[4], S Mercé[4]

[1]Center for Research and Innovation on Bioengineering, Universidad Politécnica de Valencia, Spain
[2]Instituto Tecnológico de Morelia, México
[3]Hospital Provincial de Castellón, Valencia, Spain
[4]Mercé V Electromedicina, Valencia, Spain

Abstract

Aortic arterial stiffness is an independent predictor of cardiovascular risk. Pulse wave velocity (PWV) is the most validated and universally accepted measure of arterial stiffness. The Digital Volume Pulse (DVP) is an accurate and non invasive method to obtain information on the pressure pulse waveform, and provides two indexes: stiffness index (SI_{DVP}) which relates with large artery stiffness, and the reflection index (RI_{DVP}) which relates with vascular tone. SI_{DVP} has been previously correlated with cfPWV (carotid-femoral PWV), however, the inguinal location of the employed transducer provokes a strong psychological impact on the patients, which may reduce reproducibility. By contrast, measurement of abPWV (ankle-brachial pulse wave velocity) minimizes this psychological stress. Our aim was to evaluate the relationship among blood pressure parameters and abPWV; and the relationship among abPWV, SI_{DVP} and RI_{DVP} in health subjects.

1. Introduction

Large artery damage is a major contributory factor to cardiovascular morbidity and mortality of patients with hypertension [1]. Pulse wave velocity (PWV) is know to be an indicator of arterial stiffness, and has been regarded as a marker reflecting vascular damages. Therefore, PWV has a potential application for screening vascular damage in large population [2-4]. Recent reports have shown that PWV obtained by noninvasive automatic devices (i.e. tonometry, cuff pressure) is not only a marker of vascular damages, but also a prognostic predictor in patients with hypertension or end-stage renal failure, independently of classical risk factors and PP [3,5,6]. Arterial stiffness is determined by functional and structural components related to the intrinsic elastic properties of the artery. Persistently elevated blood pressure (BP) accelerates arterial smooth muscle hyperplasia and hypertrophy, and collagen synthesis, thereby increasing arterial stiffness [6,7]. Recently, it has been reported that the validity and reproducibility of baPWV measurement are as good as those of aortic PWV or cfPWV [3]. Thus, baPWV has a potential application fore screening vascular damages in a large population [3,6]. Simultaneous measurement of brachial and ankle blood pressures enables evaluation not only of blood pressure but also pulse wave analysis [4,8]. The two indexes: ankle–brachial pressure index (ABI) and ankle-brachial pulse wave velocity (baPWV), are easily derived and are reported to be diagnostic and prognostic markers of atherosclerosis [8,9]. The digital volume pulse (DVP) is an accurate and non invasive method to obtain similar information to the peripheral pressure pulse waveform. The DVP may provides two indexes: the stiffness index (SI_{DVP}) which relates with large artery stiffness, and the reflection index (RI_{DVP}) which relates with vascular tone [10]. The influence of vascular aging on the contour of the peripheral pressure and volume pulse in the upper limb is also well recognized [11]. The change in pulse contour may be due in part to increased large artery stiffness, with an increase in PWV decreasing the time taken for pressure waves reflected from the periphery of the circulation (mainly from the lower body) to return to the aorta and thence to the upper limb [10,11]. Our aim was to evaluate the relationship among blood pressure parameters; systolic blood pressure (SBP), diastolic blood pressure (DBP), mean blood pressure (MBP), pulse pressure (PP), heart rate (HR), and abPWV; and the relationship among baPWV, SI_{DVP} and RI_{DVP} in health subjects

2. Methods

We studied 30 health voluntary subjects (10 female and 20 male, 24-52 years old). The subjects were examined in the supine position, with electrocardiogram electrodes placed on both wrists after 15 minutes rest.

The blood pressure, baPWV and DVP was measured tree times every parameter for averaging. The Acquisition of the baPWV was conducted by Pulses Trace PWV (Micro Medical, Kent, U.K.). This equipment uses a 4 MHz Doppler probe for identify the arrival of the arterial pulse. The waveform was measured sequentially in two locations (from right brachial to right ankle) of the arterial tree and timing using the R wave of the ECG as show in figure 1. The transit time (ΔT) was computed from the foot-to-foot time difference between brachial and ankle waveforms timing by R wave of the ECG. The Pulse Trace PWV automatically detects the foot-to-foot of the waveform. The baPWV is automatically calculate by the Ec.1 dividing the externally measured distance (Lba) between brachial-ankle location by the ΔT [12].

$$PWV = Lba / \Delta T \qquad \text{Ec.1}$$

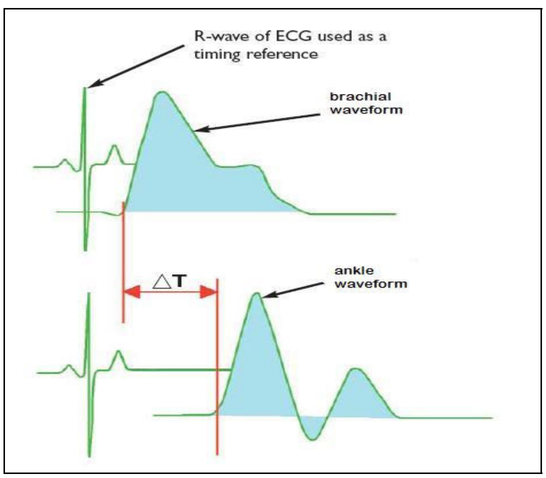

Figure 1 Example of signals detected by Doppler probe (brachial and ankle waveform) the R wave of ECG is used as timing reference to calculate ΔT.

The distance Lba between the measuring sites (i.e. the brachial and posterior tibial arteries) was measured with a tape measure. To reduce the influence of body contours on the measure distance, the tape measure is held above the surface of the body parallel to the plane of the examination table. Five partial distances are measured see fig 2: 1) from suprasternal notch to inferior edge of the umbilicus; 2) from the inferior edge of the umbilicus to the iliac crest; 3) from to the iliac crest to the medial malleolus in sampling site on the right leg; 4) from suprasternal notch to heat of humerus; and 5) from heat of humerus to the forearm. Then the distance (Lba) was calculated by subtracting the distance between the suprasternal notch to medial malleolus site on the posterior tibial artery, from the distance between suprasternal notch to the forearm site on the brachial artery. The DVP waveform was obtained by the using a Pulse Trace PCA (pulse contour analysis) (Micro Medical, Kent, U.K.) which employs a photoplethysmograph (PPG) transducer transmitting IR

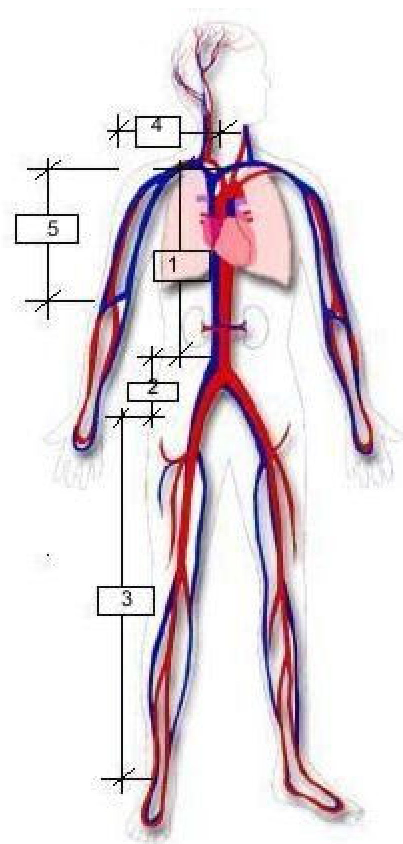

Figure 2 Measure of distances to calculate the right brachial–ankle distance (Lba).

light at 940 nm. The PPG transducer was placed on the index finger of the right hand. The figure 3 shows a typical signal of DVP. The Pulse Trace PCA derives two indices from the DVP. The stiffness index (SI) in m/s, see Ec.2 is defined as the patient's height (h) divided by ΔT_{DVP}.

$$SI = h / \Delta T_{DVP} \qquad \text{Ec.2}$$

And the reflection index (RI) (see Ec.3) is defined as the relative height of the second peak (b) (see figure 3) or inflection point expressed as a percentage

$$RI = b/a \times 100\% \qquad \text{Ec.3}$$

Statistical analysis was performed using SPSS 13 software package (SPSS, Chicago IL. USA). Pearson's correlation analysis was do it. Values of $P<0.05$ were considered to indicate statistical significance.

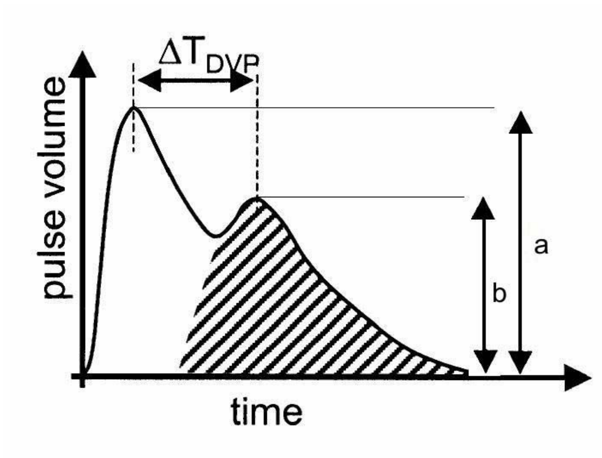

Fig 3 Depict the typical waveform of the DVP and its characteristic parameters as: time between the first and second tip (ΔT_{DVP}), amplitude of the first tip identified by (a), amplitude of the second tip identified by (b).

3. Results

Subject characteristics are presented as mean ± standard deviation table 1.

Table 1 Subject characteristic

Characteristic	Mean	S.D.
SBP	113.04	13.509
DBP	67.78	7.382
MBP	82.86	8.998
PP	45.26	8.538
HR	61.96	7.901
baPWV	8.376	1.563
SI	6.461	0.914
RI	70.53	8.07

The table 2 shows the correlation of baPWV with blood pressure. We found that baPWV correlated well with SBP, DBP, MBP, PP. By contrast it did not correlated with HR.

Table 2 Correlation coefficients between cardiovascular parameters and brachial-ankle PWV in health subjects.

	baPWV	
	r	*P*
SBP	0.670	<0.001
DBP	0.718	<0.001
MBP	0.728	<0.001
PP	0.439	<0.05
HR	0.314	>0.05

SBP systolic blood pressure, DBP diastolic blood pressure, MBP mean blood pressure, PP pulse pressure, HR heart rate.

The table 3 shows the correlation of baPWV with stiffness index (SI), no correlated reflection index (RI): SI (r=0.573 and p=0.022), RI (r=0.323 and p=0.1).

Table 3 Correlation coefficients between DVP parameter and brachial-ankle PWV in health subjects.

	baPWV	
	r	*p*
SI	0.573	<0.05
RI	0.323	>0.05

SI stiffness index, RI reflection index.

4. Discussion and conclusions

Yamashina et al [3] compared the noninvasive baPWV with the aPWV obtained by invasive measurement in patients with coronary artery disease. They observed a good correlation between them (r=0.87 and p<0.01). This result provide an acceptable validation of the noninvasive baPWV measurement and suggest that noninvasive baPWV is an acceptable marker of vascular damages comparable to the carotid-femoral pulse wave velocity (cfPWV) obtained by other established methods. In fact Naidu et al. [13] reported than carotid-femoral pulse wave velocity (cfPWV) correlated well with baPWV in health and coronary artery disease (CAD) subjects (r= 0.99 and p<0.0001). Likewise Munakata et al. [14] reported than cfPWV correlated well with the right brachial–right ankle PWV (r=0.755, P<0.000001) and with, right brachial–left ankle PWV (r=0.778 and P<0.000001). Munakata et al [15] reported than baPWV correlated with young and old hypertensive patients. In young hypertensive: SBP (r=0.522 and p<0.000001), DBP (r=0.422 and p<0.00005), MBP (r=0.564 and p<0.000001), PP (r=0.30, p< 0.005). In old hypertensive: SBP (r=0.529 and p< 0.000001), DBP (r=0.341 and p< 0.00005), MBP (r=0.463 and p<0.000005), PP (r=0.460, p< 0.000005). Igarashi, Y. et al. [8] reported than, baPWV was correlated in coronary artery disease patients (CAD) with SBP (r=0.27 and p<0.0001). Shiotani et al [16] reported than baPWV obtained in subjects with overweight young adults correlated with MBP (r=0.65 and p<0.0001). Matsui et al [6] reported than, baPWV was correlated with SBP in hypertensive patients SBP (r=0.39 and p< 0.0001), MBP (r=0.29 and p<0.0005), PP (r=0.30 and p< 0.005). Aso et al [17] reported than baPWV was correlated in type 2 diabetic patients with SBP (r=0.61 and p<0.0001) [17]. We measure baPWV because is a parameter reliable as stiffness indicator and was not reported the correlation among cardiovascular parameters and brachial–ankle PWV in health subjects. In our study the correlation obtained between baPWV and the arterial pressure presented better coefficients of correlation to the reported ones.

Millasseau et al [10] reported than c-fPWV correlated well with SI (r=0.65 and *p*<0.0001) derivate of DVP. Only Millasseau et al have reported results on the relationship between cfPWV and SI (measured from DVP). The correlation obtained between the stiffness index (SI) and baPWV has not been reported previously.

5. Conclusions

The obtained experimental results suggest a relation among the stiffness index obtained of simple form by photoplethysmography (DVP) and the baPWV, as well as the values of sanguineous pressure. These relations can have important implications diagnose, since the DVP is obtained from simple and economic form.

Acknowledgements

This study was partially supported by Mercé V Electro medicine (Valencia, Spain).

References

[1] Blacher J, Asmar R, Djane S, London GM, Safar ME. Aortic pulse wave velocity as a marker of cardiovascular risk in hypertensive patients. *Hypertension* 1999. 33. 5; 1111-1117.

[2] Lehmann ED. Clinical value of aortic pulse-wave velocity measurement. *Lancet* 1999. 354. 9178; 528-529.

[3] Yamashina A, Tomiyama H, Takeda K, Tsuda H, Arai T, Hirose K, et al. Validity, reproducibility, and clinical significance of noninvasive brachial-ankle pulse wave velocity measurement. *Hypertens.Res.* 2002. 25. 3; 359-364.

[4] Asmar R, Benetos A, Topouchian J, Laurent P, Pannier B, Brisac AM, et al. Assessment of arterial distensibility by automatic pulse wave velocity measurement. Validation and clinical application studies. *Hypertension* 1995. 26. 3; 485-490.

[5] Laurent S, Boutouyrie P, Asmar R, Gautier I, Laloux B, Guize L, et al. Aortic stiffness is an independent predictor of all-cause and cardiovascular mortality in hypertensive patients. *Hypertension* 2001. 37. 5; 1236-1241.

[6] Matsui Y, Kario K, Ishikawa J, Eguchi K, Hoshide S, Shimada K. Reproducibility of arterial stiffness indices (pulse wave velocity and augmentation index) simultaneously assessed by automated pulse wave analysis and their associated risk factors in essential hypertensive patients. *Hypertens.Res.* 2004. 27. 11; 851-857.

[7] Nichols WW, O'Rouke M. McDonald's Blood Flow in Arteries : Theorical, Experimental and Clinical Principles, 4ht ed. London, Eduard Arnold 1998. 1998.

[8] Igarashi Y, Chikamori T, Tomiyama H, Usui Y, Hida S, Tanaka H, et al. Diagnostic value of simultaneous brachial and ankle blood pressure measurements for the extent and severity of coronary artery disease as assessed by myocardial perfusion imaging. *Circ.J.* 2005. 69. 2; 237-242.

[9] Pearson TA. New tools for coronary risk assessment: what are their advantages and limitations? *Circulation* 2002. 105. 7; 886-892.

[10] Millasseau SC, Kelly RP, Ritter JM, Chowienczyk PJ. Determination of age-related increases in large artery stiffness by digital pulse contour analysis. *Clin.Sci.(Lond)* 2002. 103. 4; 371-377.

[11] Kelly R, Hayward C, Avolio A, O'Rourke M. Noninvasive determination of age-related changes in the human arterial pulse. *Circulation* 1989. 80. 6; 1652-1659.

[12] Micro Medical Limited. Micro Medical Pulse Trace PWV and Micro Medical Pulse Trace PCA.www.micromedical.co.uk . 1-2-2006.

[13] Naidu MU, Reddy BM, Yashmaina S, Patnaik AN, Rani PU. Validity and reproducibility of arterial pulse wave velocity measurement using new device with oscillometric technique: a pilot study. *Biomed.Eng Online.* 2005. 4. 49.

[14] Munakata M, Ito N, Nunokawa T, Yoshinaga K. Utility of automated brachial ankle pulse wave velocity measurements in hypertensive patients. *Am.J.Hypertens.* 2003. 16. 8; 653-657.

[15] Munakata M, Nunokawa T, Yoshinaga K, Toyota T. The Brachial-Ankle Pulse Wave Velocity is Better Predictor for Pulse Pressurethan Augmentation Index in Older Hipertensives. *J.Med.Ass.Japan* 2005.

[16] Shiotani A, Motoyama M, Matsuda T, Miyanishi T. Brachial-ankle pulse wave velocity in Japanese university students. *Intern.Med.* 2005. 44. 7; 696-701.

[17] Aso K, Miyata M, Kubo T, Hashiguchi H, Fukudome M, Fukushige E, et al. Brachial-ankle pulse wave velocity is useful for evaluation of complications in type 2 diabetic patients. *Hypertens.Res.* 2003. 26. 10; 807-813.

E-mail: jmpadilla62@msn.com
juapaher@doctor.upv.es