COMPARISON OF ARTERIAL RELAXATION TIME IN NORMOTENSIVE AND HYPERTENSIVE SUBJECTS

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ABSTRACT

Arterial stiffness is emerging as an important determinant of increased systolic blood pressure (SBP) and pulse pressure in the aging population. Arterial stiffness in the brachial artery was studied in both normotensive (n=6) and hypertensive (n=4) subjects. The normotensive subjects have SBP/DBP of less than 120/80 mm Hg. They are divided into two age groups, four subjects are between 19 to 23 years old and two are 57 and 60 years old. The hypertensive subjects are aged between 48 to 58 years old, with elevated SBP (ranging from 130-168 mm Hg) and are currently on hypertensive medication. Temporal measurements of the pressure and volume waveforms were recorded from both the left and right hands of the subject, with one arm at heart level and the other initially at heart level and then raised to a height of 35 cm above heart level. Upon raising the arm, a delay was observed in the pulse measurement of the raised arm relative to the hand at heart level. The delay has previously been shown to decay exponentially with time. For the normotensive subjects, the average pressure and volume relaxation times, τ_P and τ_V, were 75 s and 41 s for the younger-age group and 86 s and 68 s for the older-age group, respectively. The delay times for subjects in the hypertensive group were assumed to approach the baseline asymptotically. The validity of this assumption has been demonstrated in the control group. The average τ_P value in the hypertensive group was found to be 581 s, significantly higher than that of the control group.

BACKGROUND

Arterial stiffening is an important determinant of increased systolic blood pressure (SBP) and pulse pressure (PP) in the aging community. It is related to cardiovascular complications and events, including left ventricular hypertrophy and failure, and aneurysm formation and rupture. It is a major contributor to atherosclerotic and small vessel disease, stroke myocardial infarction, and renal failure [1,2]. The identification of risk factors for atherosclerosis development contributes significantly to the prevention and treatment of cardiovascular disease (CVD). Early detection of arterial stiffening helps to reduce medical costs, time spent in surgery, and patient suffering. Three noninvasive techniques, flow-mediated dilation (FMD), pulsewave velocity (PWV) measurement, and measurement of the thickness (IT) of the carotid intima, are used as markers of atherosclerosis. Both IT and FMD measurements require brightness mode ultrasound, while PWV is a timing measurement.

FMD of the brachial artery is the most commonly used technique to infer epithelial function. Brachial artery FMD is typically determined using ultrasound measurement of the dilation of brachial artery diameter after a 5-min occlusion using a blood pressure cuff. Endothelial dysfunction is demonstrated when a reduced dilation is observed. FMD is reduced in individuals with atherosclerosis and with coronary risk factors. It improves with risk-reduction therapy. Malik et al. [3] showed that reproducibility of post-ischemic peak blood flow is superior to that of FMD in healthy volunteers. However, their measurements have low reproducibility and are in contrast with those obtained by others.

Moens et al. [4] examined the limitations of the most common type of ultrasound used in FMD measurements and reported that the ultrasound system is capable of distinguishing two adjacent points located at 0.2 mm apart. To show a dilation of 5% in a brachial artery (assuming a diameter of 5 mm), a resolution of 0.25 mm is required. One needs to apply advanced signal processing to reliably detect such a dilation. The oval-shaped cross-section of the brachial artery poses a challenge in accurately measuring FMD. Two studies [5,6] have shown that the position of the blood pressure cuff affects the accuracy of the FMD measurements. Occlusion with the cuff placed on the upper arm results in significantly greater blood flow than that observed with the cuff placed on the forearm.

Tschakovsky and Highson [7] demonstrated that venous emptying is a stimulus for vasodilation. They applied Doppler ultrasound (4 MHz) to measure brachial artery blood flow and blood velocity in both resting (horizontal) and elevated forearm, for different arm-raise durations, 4 s and 2 min. A 7.5 MHz echo Doppler probe was used to measure the diameter of the brachial artery.

OBJECTIVE

There is no economically and/or universally accepted means of screening patients for atherosclerosis or peripheral arterial disease (PAD). This paper describes a simple technique based on timing measurements of the pulse waves to infer the conditions of peripheral arteries. The temporal characteristics of pressure and volume pulse waveforms are measured using commercial off-the-shelf sensors. This method has the potential to fill a critical need of providing an office-based marker for assessing arterial stiffness.

PROCEDURE

The subject was seated with a pressure sensor (Model 1010 piezoelectric transducer from UFI, California, USA) and an 800-nm optical sensor (Model 1020 infrared reflective sensor from UFI) attached to each hand. Data acquisition was trigger using an arterial pulse. Outputs of the sensors were delivered to a 4-channel digital storage oscilloscope (Model TDS2014B from Tektronix, Oregon, USA), digitized (8 bits), stored, and displayed. Data from the scope were then transferred to a PC using a custom Visual C++-based data acquisition program. The PC armed the oscilloscope, which was then triggered by the next arterial pulse.

The oscilloscope time base was set to obtain data points separated by 1 ms. With proper triggering, this setting corresponds to the observation of three pulses. The subject sat with both hands at heart level (control position) for 1 min, followed by raising the right arm at a 45° angle for about 500 sec. Data were collected continuously during the entire measurement session. Using the oscilloscope for data acquisition allows one to observe all the pulse traces visually and to adjust amplitude settings as necessary during measurements. However, some data were inevitably missed during the transfer of data from the oscilloscope to the PC. The data were filtered using a 4th order Savitzky-Golay filter and normalized. The peaks were then located and the delays relative to the left-hand pressure sensor were computed.

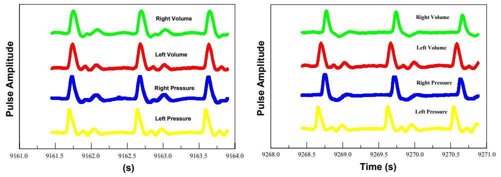

Fig.1. Filtered pulse data with both hands at heart level (left) and with right arm raised at a 45° angle.

DATA

The data were processed using the Savitzky-Golay filter before the determination of peak locations and the measurements of full-width-at-half-maximum (FWHM) using a verified and validated algorithm. The delay times are defined as follows:

Left:	peak time of left pressure pulse – peak time of left volume pulse
Right:	peak time of right pressure pulse – peak time of right volume pulse
Pressure:	peak time of left pressure pulse – peak time of right pressure pulse
Volume:	peak time of left volume pulse – peak time of right volume pulse

When the subject's hands were at control positions, the left and right delay times were found to be about equal (±1 ms), and the pressure and volume delay times were zero. When the right arm was raised, increases in the pressure and volume delay times were observed. The delays decreased exponentially with time. The volume delay was greater than that of the pressure delay, resulting in an increase in the delay in the left arm. Figure 2 shows a typical data set

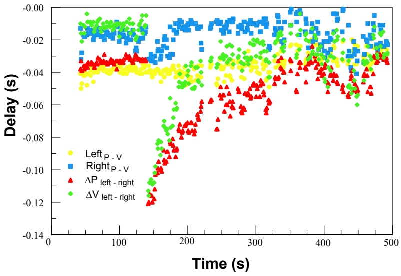

Fig. 2. Data obtained from a 19-year-old Caucasian female, with her right arm raised at a 45° angle at time = 98 s.

DATA ANALYSIS

Tschakovsky and Hughson [7] have shown that emptying of the vein by raising one's arm acts as a stimulus for the dilation of the brachial artery. The combination of the brachial artery dilation and the constant cardiac output results in a decreased blood velocity in the right arm and a delay in the detection of the pulse waveform in that arm as compared to the left arm. After the sudden dilation, the brachial artery relaxes back to its pre-dilated diameter as indicated by the delay approaching that of the baseline value as shown in Fig. 2. The delay times were fit to an equation of the form:

$$Y_X(t) = A_X + B_X \exp(-(t - t_0) / \tau_X) \quad (1)$$

where A and B are constants, t_0 is the time when the arm is raised, τ is the relaxation time of the brachial artery, and X denotes either the pressure wave P or the volume wave V. The values of τ_P and τ_V of the test subjects are listed in Table I.

Subject	Age	Gender	SBP (mm Hg)	DBP (mm Hg)	τ_V (s)	τ_P (s)
1	19	F	90	66	35.2	90.9
2	19	F	102	75	42.6	71.9
3	22	F	110	76	38.7	61.1
4	23	M	131	84	50.8	77.5
5	57	F	126	73	79.9	103.2
6	60	M	105	70	55.5	68.2

A limited sample of four hypertensive subjects was examined to compare the values of relaxation time with those of the normal subjects. All four hypertensive subjects had been on medication for high blood pressure for at least five years. Three of the subjects were morbidly obese and the fourth was overweight. Two of the obese subjects had an SBP greater than 140 mm Hg. The average τ_P for the hypertensive population was 584 ± 116 s.

COMPARISON WITH FMD

A comparison with FMD was performed by examining the delay time. If the arterial flow is assumed constant before and after the arm is raised, then:

$$\text{Flow} = V_1\, \pi R_1^2 = V_2\, \Pi\, R_2^2 \quad (2)$$

where V_1 and R_1, and V_2 and R_2 are the blood velocity and brachial artery diameter with the arm at heart level and in the raised position, respectively. The time delay, ΔT, between the left and right arms is given by:

$$\Delta T = L / V_1 – P / V_2 \Rightarrow V_1\, \Delta T / L = X^2 - 1 \quad (3)$$

where $X = R_2 / R_1$ and L is the path length (35 cm). Using ΔT = 0.12 s (Fig. 2), R_1 = 4.0 mm, and V_1 = 18 cm/s [8], the arterial dilation is given by X – 1 = 3%.

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