Waveform Analysis of Peripheral Pulse Wave Detected in the Fingertip with Photoplethysmograph

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Abstract *- The aim of this study was to study the elastic properties of vascular tree noninvasively in human subjects as a function of aging using the shape of peripheral pulse wave. We used 21 subjects in two age groups, 22-30, 37-72 years. The peripheral pulse has a steep rise and a notch on the falling slope in the younger subjects. With older subjects a more gradual rise and fall and no pronounced dicrotic notch were observed. The analyzing program calculated ratios t2/t1, P2/P1 and V/P1. As a result, the ratios t2/t1 (p<0.002) and V/P1 (p<0.02) were significantly different between the groups. Two of them could provide a simple, noninvasive means for studying changes in the elastic properties of the vascular system, depending on the age and disease.*

Keywords: pulse wave, photoplethysmograph, pulse wave velocity (PWV), arterial compliance, aging, arterial stiffness.

1 Introduction

Pulse wave analysis helps to study large-artery damage, a major contributor to cardiovascular disease which is the common cause of mortality and morbidity in industrialized countries. This high incidence emphasizes the importance of early evaluation of the arterial abnormalities which constitute the common lesion of major organ damages due to cardiovascular risk factors [1,2]. Several studies conduced with various groups of population showed significant correlations or powerful interactions between PWV (and other parameters concerning arterial wall circumstances) and the so-called "major" cardiovascular risk factors, such as hypertension, high cholesterol level, diabetes and smoking. Impaired vascular compliance and a concurrent rise in vascular rigidity are the central pathogenetic processes and the first step leading to fatal cardiovascular events in many cases of hypertension and hyperlipidaemia patients. Several methods can be used to analyze the structure and function of the large arteries. Among the noninvasive methods of evaluating arteries, pulse wave analysis can be used as an index of arterial elasticity and stiffness [3]. The electrical signal from the photodetector is related to blood volume changes in tissue. This signal provides a means of determining properties of vascular tree during the cardiac cycle and changes with aging and disease [4,5].

2 Methods

2.1 Measurement system

A schematic diagram of the equipment used is shown in Figure 1. For photoplethysmographic (PPG) measurements the finger clip sensor (Nellcor Durasensor analog) was used (Fig. 1, block 1). The special laboratory instrument for PPG signal amplifying was designed (block 2). The scheme contains two Light Emitting Diodes (LED): red and infrared. The current in LEDs is limited by consistently connected resistor 150 ohm. Both LEDs are multiplexed on two contacts of the sensor. By changing polarity of a current it is possible to switch LEDs, but it is impossible to run both simultaneously. A special National Instruments data acquisition board (DAQ) PCI-MIO-16E-1 (block 3) to digitize the signals locally and transmit the digital data to the personal computer with sampling rate 500

Hz and amplitude ±2.5 V is used in this system.

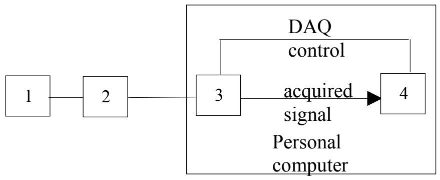


Fig. 1. Block diagram of the equipment.

Signals from finger sensor are amplified by the PPG signal amplifier and then the signal is directed to the DAQ board where acquisition and analog-to-digital conversion take place. Once data is acquired and received it is possible to process and manipulate it. The LabVIEW software packet (block 4) consists of the following programs: main program for data acquisition; program for signal analysis; program for calculations.

2.2 Physiological measurement

Photoplethysmographic signal measurements were obtained from 21 subjects (13 male, 8 female). Subjects were divided into two age groups, 22-30 years (13 individuals, further Group 1) and 37-72 years (8 individuals, Group 2). Measurements were performed in a laboratory. Each subject was asked to relax and sit on the chair and rest the forearm on the lab table to help the entire hand keep steady. An operator then attached the finger sensor to the forth finger tip of the left hand. It is important to have a comfortable arm position in order to keep the finger relatively motionless for a stable and repeatable recording. The length of the recorded signal was 20 seconds.

2.3 Analysis

The waveform analysis was performed to assess the PPG characteristics. The waveforms were analyzed offline using LabVIEW programs. The computer program displayed the incoming waveform on the screen of the computer. The minimum and maximum threshold (further P1 and P2) and valley (V) values were used as marks for signal analysis and comparison. To locate necessary points of signal five markers were used. Marker 1 characterizes the location of the first foot of the pulse. Marker 2 characterizes the location of the first peak. Marker 3 characterizes the location of the second peak. Marker 4 characterizes the location of the valley. Marker 5 characterizes the location of the second foot (Figure 2).

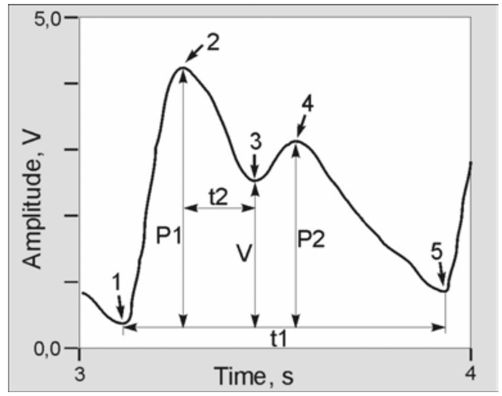


Fig. 2. Example of PPG signal pulses recognition.

The program enables the calculation of the peaks ratio (P2/P1) (amplitude foot to peak 1, giving P1; amplitude foot to peak 2, giving P2), the ratio (V/P1) (amplitude foot to valley, giving V; amplitude foot to peak 1, giving P1), the times ratio (t2/t1) between peaks (time peak to peak,). The length of the recorded signal is 20 seconds. It means that at an average pulse rate, the number of the periods in one recorded signal is 25. The process of transition from one pulse to another was manual, which allowed editing of any poorly recognized pulse landmarks. Due to movement or irregular breathing anomalous pulses were rejected from the analysis. A 20s epoch of PPG signal were manually extracted for the analysis. Tacking each foot as a reference, the foot-to-peak amplitudes of the first and second peaks were calculated beat-by-beat. The mean values defined the baseline of the measures. Then the ratios P2/P1, t2/t1 and V/P1 were calculated.

3 Results

The main objective of this thesis was to determine how the pulse shape changes as a function of age. The difference in the signal shape can be well observed visually (Figures 3, 4). In the younger subjects, the signal had a steep rise and a notch on the falling slope. In the older subjects, a more gradual rise and fall and no pronounced dicrotic notch were observed.

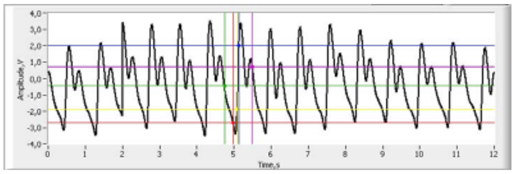


Fig. 3. PPG signal for a 22 –year-old female.

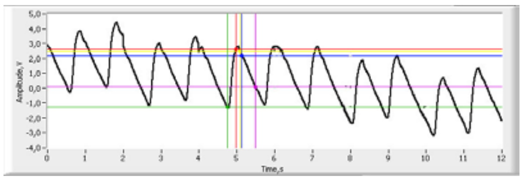
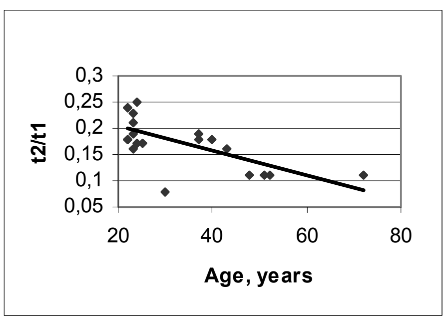


Fig. 4. PPG signal for a 51 –year-old male.

3.1 Waveform analysis results

Figure 5 (a) shows the age dependence of the ratio t2/t1. This ratio is decreasing with age. For the subjects in the group of age 20-30 years, the ratio remains nearly 0.15-0.25, except one subject. During the decrease with age, the t2/t1 starts to decrease to the nearly 0.11.



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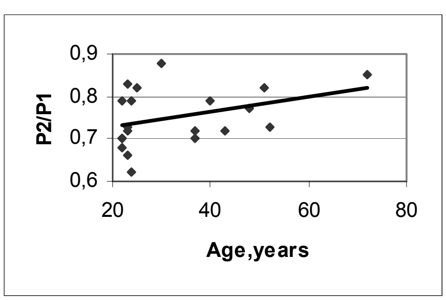

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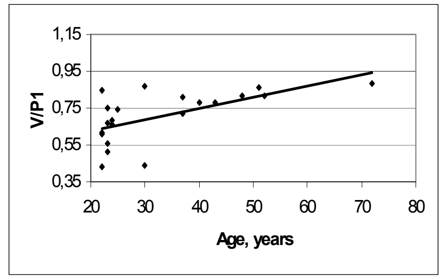

c

Fig. 5. (a) the relationship between t2/t1 and age; (b) the relationship between P2/P1 and age; (c) the relationship between V/P1 and age.

Figure 5 (b) shows the age dependence of the ratio P2/P1. We cannot see a strongly pronounced relationship. A slight increase in the ratio occurs with a decrease in the age. Probably this ratio does not depend on the age.

Figure 5 (c) shows the age dependence of the ratio V/P1. It can be seen how the ratio V/P1 increases with age that means that this method works.

Differences in the ratios P2/P1, t2/t1 and V/P1 between age groups were compared using the statistical program ANOVA (Table 1). This analysis tool performs a simple analysis of variance (ANOVA). The P column gives a P-value (Probability value) for rejection of the null hypothesis that the parameter is zero (i.e. not a significant linear factor). As a result of this work, two ratios were significantly different in terms of statistics at $p<0.05$ as shown in Table 1. The ratios t2/t1 and V/P1 were significantly different between the groups. That means that ratios t2/t1 and V/P1 can be used to analyze distensibility of arteries.

Table1. Significance of difference in ratios between age groups.

Ratio	P -value
t2/t1	0.001517 *
V/P1	0.017944 *
P2/P1	0.130175

*Statistically significant difference at >95% confidence level.

4 Discussion and conclusions

The main difference of a signal in Group 2 was the change of the position of the second peak (shifting aside the first peak). In some cases, it was difficult to distinguish dicrotic notch visually. In fact, it is well established that the pulse wave must be analyzed as a superposition of two separate waves: the incident traveling wave from heart to periphery, and the reflected wave traveling from the periphery and the site of wave reflection to the heart. The incident wave depends on the left ventricular ejection and the arterial stiffness, whereas the reflected wave is related to arterial stiffness and the potential sites of wave reflection. In the young adults, where arteries are distensible, the pulse wave velocity is relatively low. In older subjects, where the arteries are less distensible the pulse wave velocity is high. This characteristic change in the shape of the pulse wave with the age is attributed to an increase in aortic stiffness and pulse wave velocity, with earlier return of reflected waves from peripheral sites. Pulse wave velocity has been found to increase with aging. As vessels get stiffer during the aging process, the reflected wave returns faster and due to the summation of waves the resultant pulse wave changes [6]. So, the interval between the first and second peaks changes (decrease), and the amplitude of the second peak changes too (decrease), as a result, the pulse wave lacks a dicrotic notch and is more rounded in shape, because the reduced wave reflection. In summary, comparison of the three methods of an estimation of the signal shape shows that two of them can provide a simple noninvasive means for studying changes in the elastic properties of the vascular system with the age. That means that a decrease in the ratio t2/t1 occurs with an increase in the age. The smaller this number, the stiffer arteries are. The increase of ratio V/P1 happens with increase of age [7]. The greater this number the stiffer arteries are.

Further tests in a clinical environment are necessary to classify various pathological conditions with the waveform analysis. We suggest that this type of analysis can provide a simple inexpensive and noninvasive means for studying changes in the elastic properties of the vascular system with the age and disease.

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5 References

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