A Bio Signal Processing System for Pulse Wave Velocity Detection

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Abstract **- Pulse wave velocity (PWV) is the most popular index to assessment the arterial stiffness. Currently, several non-invasive examination methods with single channel for PWV are announced. This paper proposes a non-invasive digital volume pulse (DVP) measuring system using a dual channel simultaneous measurement method try to meet the demands for home healthcare equipment which is easy to operate. Through synchronal technical in measuring DVP signals from finger and toe can achieves more precise time and substantially reduces the time spend in measurement procedures. In addition, the proposed system assessed from dual-channel PPG is well correlated with the traditional method and can be used for evaluating cardiovascular risk factors.**

Index Terms - Pulse wave velocity, arterial stiffness, photoplethysmography , digital volume pulse.

INTRODUCTION

Cardiovascular disease is one of major cause of morbidity and mortality in the world. In the recent year, there has been much interest in the relationship between arterial stiffness and cardiovascular disease. Many researches report increased stiffness of the large arteries is associated with increased cardiovascular risk. An elevated aortic pulse wave velocity (PWV) is not only associated with increased cardiovascular risks, but also plays a prognostic factor in patients with end-stage renal disease [1-7]. Arterial stiffness increases with age and concomitant cardiovascular risk factors [8-12]. Systolic, diastolic, and pulse pressures are also related to the physical properties of elastic arteries, has been directed toward as cardiovascular risk factors [1-3, 13]. Though manometer-tipped catheters enable precise measures of vascular stiffness at specific regions of vessels, these approaches have limited clinical utility. Some studies involving PWV, a surrogate measure of arterial stiffness, indicate that it increases with age. PWV is a more valid marker of arterial stiffness than pulse pressure, and several studies have demonstrated that PWV is a more powerful predictor of cardiovascular events than pulse pressure. Noninvasive methods include cross-sectional echocardiography, magnetic resonance imaging, applanation tonometry and pulse trace etc. However, the above instruments are too expensive to appropriate for home health-care.

In the study of Blacher et al, it was found that PWV values superior to 13 m/sec were associated with an increase in cardiovascular mortality [1]. Laurent et al demonstrated that in hypertensive subjects, a 5m/sec increase in arterial stiffness is associated with a 50% increase in cardiovascular mortality [2]. As changes can be detected before the appearance of clinically significant vascular disease, arterial stiffness may act either as a marker for the development of future atherosclerotic disease or may be more directly involved as a causative factor in the process of atherosclerosis. The PWV is a marker of the elasticity of elastic or muscular arteries, and reflects mainly the mechanical properties of the arterial wall. Diffuse sclerotic changes of the arterial wall observed in degenerative or pathological cases increase the arterial stiffness. PWV is now recognized as a standard method for measurement of arterial stiffness.

Traditionally, the carotid femoral PWV has been used to evaluate aortic stiffness because 1) the pulse wave can easily be recorded at these two sites and 2) the distance between these two sites is great enough to allow an accurate calculation of the time interval between the two waves. However, detection of the pulse waveform requires specific training and subsequent certification. In view of this, a reliable PWV-measured device that requires no specialized technical skill seems necessary. New techniques should be applied to evaluate cardiovascular risk in patients, particularly those that can be identified easily in home. A digital volume pulse (DVP) can be obtained using photoplethysmography (PPG). The DVP can be rapidly and simply detected by measuring the transmission of infrared light through the finger pulp. Some previous studies have demonstrated that the contour of DVP is similar to that of a peripheral pressure pulse [14-17]. The contour of the DVP is determined by the systemic circulation including pressure wave reflection and PWV in the aorta and large arteries. This novel method has been developed to measure PWV directly from DVP. Given that the contour of DVP is similar to peripheral pulse, the time difference between two different DVP sites can be regarded as the transit

time between two pulses. The PWV can then be calculated by dividing the distance between these two sites by the transit time. To automate and facilitate the process, a system has been developed featuring two PPG sensors that detect DVP from two different sites simultaneously; in addition, this system has software that analyze the DVP and measure exactly the time difference between these two DVP roots.

The proportion of people in the world with risk factors for arteriosclerosis, such as elevated serum cholesterol levels and diabetes, has been increasing in recent years. It is due to changes in their eating habits and decrease in the level of physical activity. For the reason, we hope that a PC-based device to measure PWV by using PPG method can be developed. The PWV is calculated from measurements of pulse transit time and path length between the finger and toe sites. Obtaining the PWV measurement using this device is easy and time saving because no specialized skills are needed to use it. The goals of this study were 1) to develop a convenient and non-expensive PWV measurement instrument that people can use in home and 2) to evaluate the validity and reliability of the developed instrument.

METHODS FOR PWV DETECTION

To test the validity of our new method, this new system was used to detect the PWV in asymptomatic subjects, and results were compared with those obtained with the standard method based on Pulse Trace system (Micro Medical, Gillingham, Kent, UK). A total of 183 asymptomatic subjects (mean age 28 ± 12 years) were included in this study. All subjects were apparently healthy and free of any vascular disease symptoms. All subjects were in normal sinus rhythm and gave their written informed consent for this study. Before any testing, all subjects rested in a supine position for 20 min in a quiet, temperature-controlled (26°±1°C) room. The PWV was measured both by our dual-channel PPG system (represented as PWV-DVP) and by Pulse Trace PWV (represented as PWV-PT). To test the reproducibility of our new method, PWV-DVP of 30 subjects were measured twice with a two-day interval.

Determination of PWV with Dual-Channel PPG System

This new PWV measurement system was consisted of portable interception device and pulse wave analytic software. The interception device is a PPG with two infrared sensors emitting a wavelength of 940 nm. Signals detected by infrared sensors are transmitted to a signal-processing unit with analog-to-digital and filter circuit. MSP430F149 (Texas Instruments Incorporated, USA) was used as mixed signal processor. It is micro-controller configurations with two built-in 16-bit timers, a fast 12-bit A/D converter, 60kB flash memory, 2KB RAM and 48 I/O pins (Fig. 1). The pulse wave analytic software uses a Visual Basic interface (Microsoft Corporation, Redmond, WA) that can analyze two DVP simultaneously and measure the time difference between the two roots of DVP (Fig. 2).

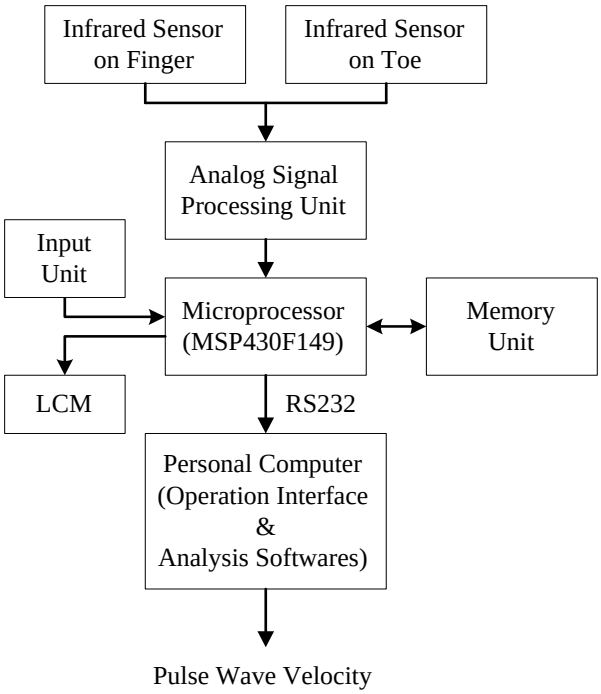

Fig. 1. The Block Diagram of the Dual-Channel PWV Measurement System

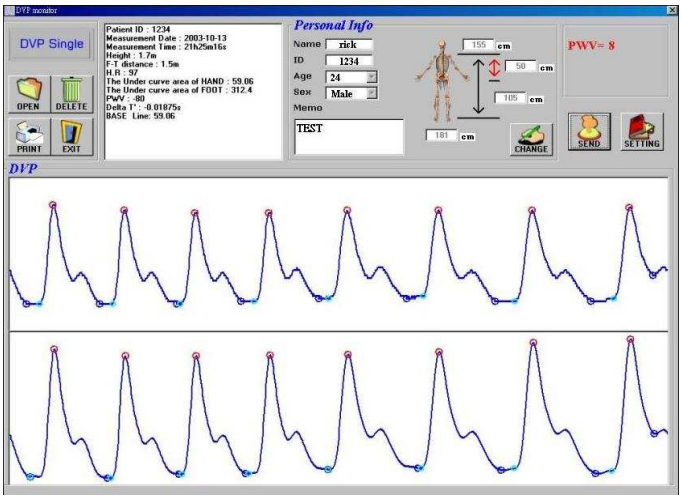

Fig. 2. Transit time between two digital volume pulses is automatically detected

One infrared sensor is placed on the right index finger and the other is placed on the right second toe. For each measurement, DVP are recorded simultaneously from both sites for a 5-sec duration. The transit time is calculated as the average of all time differences measured during this 5-sec period. The finger-to-toe distance is the difference on the distance measured from the sternal notch to the right index toe and from the sternal notch to the right index finger. The software automatically calculates PWV after the finger-to-toe distance measurement is entered.

Determination of PWV with Micro Medical Pulse Trace System

To test the validity of the new system, PWV was also determined with Micro Medical Pulse Trace system. Pulse Trace PWV uses the standard Doppler method to detect the onset of flow in the artery. Doppler pulses are recorded sequentially in 2 different arterial sites and compared using the R-wave of the ECG, which is used as a timing reference. Aortic arterial stiffness as measured by PWV between the carotid and femoral arteries is an independent predictor of cardiovascular risk.

Statistical Analysis

The significant difference between PWV-DVP and PWV-PT was analyzed by paired-samples t-test with 95% confidence interval (95% CI). The correlation between PWV-DVP and PWV-PT was also analyzed by Pearson correlation with two-tailed test of significance. Data are presented as the mean ± standard deviation. All data were recorded and analyzed using the SPSS statistical package, version 12.0 for Windows (SPSS Inc., Chicago, Illinois). A P value < .05 was regarded as statistically significant.

EVALUATION AND RESULTS

We studies 183 normotensive patients (BP < 130/90 mmHg, all men), mean age 28 ± 12 years. The patients had no signs, symptoms, or history of cardiac or renal failure and coronary insufficiency. To improve the reliability of experimental results, every data was used with average of 3-times measure. In the group of 30 subjects with repeated PWV-DVP measurements, there was good agreement between two PWV evaluations (6.16 ± 1.35 vs. 6.20 ± 1.36 m/sec, r = 0.91, P < .01). Besides, the experimental results were similar for measurement by the design system and medical standard instrument—Pulse Trace PWV. The PWV-DVP was significantly correlated with PWV-PT (r = 0.836, P < .01) (Fig. 3). There was no significant difference between the two measurement results (6.19 ± 1.40 vs. 6.26 ± 1.60 m/sec, P > .01).

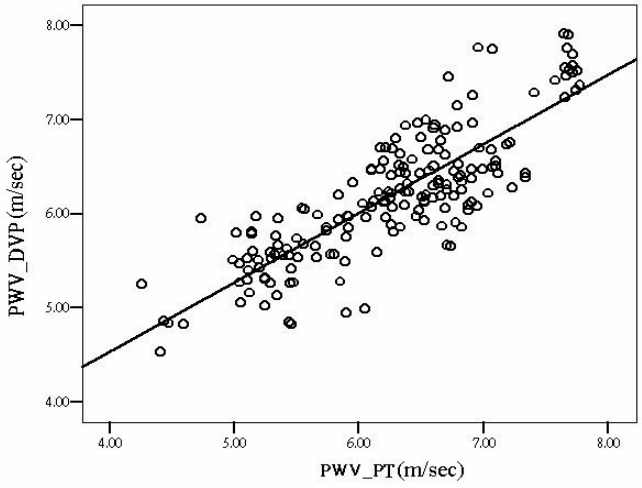

Fig. 3. Pulse wave velocity measured by dual-channel system is significantly correlated with traditional method. PWV-PT = pulse wave velocity by Pulse Trace PWV; PWV-DVP = pulse wave velocity by digital volume pulse.

Among various indices of arterial stiffness, PWV is a reliable and reproducible method. Woodman et al. reported that the coefficient of variation (CV) for repetitive examinations was lowest for central PWV and was significantly lower than other stiffness indices. All measures of arterial stiffness were significantly correlated with central PWV. PWV has been studied extensively for assessing the cardiovascular risks in various conditions. Two major drawbacks of the standard method, however, are the expensive equipment needed and the high level of technical expertise needed for obtaining an adequate waveform for analysis.

Photoplethysmography is a noninvasive method for evaluation of peripheral hemodynamics and recently the application of PPG has been extended to arterial function, including arterial stiffness and endothelial function. In the study, the new method was developed using a dual-channel PPG with good reproducibility for measuring PWV. The PWV detected by the new method was well correlated with that obtained by the standard method. The DVP signal from PPG has certain limitations in the study. The amount of reflected light depends on several factors, including degree of skin pigmentation, individual tissue characteristics, and initial blood volume in the measured area. Our study data are also confined to asymptomatic subjects with normal sinus rhythm and no concomitant obvious atherosclerosis. However, our method was not applied to patients with diseases in peripheral circulation.

It is important to test our method in different situations in the future. Therefore, our new method should be further validated in patients with different etiologies and diagnoses, and should be tested for clinical significance in regard to prognosis and response to therapy.

A non-invasive measurement device for cardiovascular arteriosclerosis evaluation is proposed in this paper. This system uses dual-channel data acquisition technology, which can simultaneously measure DVP signals of fingers and toes without medical professionals to participate in the whole measurement process. Moreover, the data acquisition can be obtained without external equipment with assistance to 3-leads electrocardiograph recording. This system has 2 advantages: (1) Using a dual-channel PWV measurement method would decrease the measurement time by using simple operation procedures; (2) It is cost reduced that the PWV can be evaluated without ECG location.

CONCOLUTIONS

The PWV assessed from dual-channel PPG is well correlated with the traditional method and can be used for evaluating cardiovascular risk factors. In comparison with micro medical pulse trace system, our new system is advantageous in terms of lower expense (about 250 vs. 11,000 US dollars), complete technical development, portability and compatibility of PC human interface. Only two PPG sensors, an analog-to-digital circuit for signal processing, and a notebook/personal computer are needed.

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