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Non-invasive Studies on Age Related Parameters Using a Blood Volume Pulse Sensor

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A non-invasive technique is implemented to measure a parameter which is closely related to the distensibility of large arteries, using the second derivative of the infrared photoplethysmographic waveform. Thirty subjects within the age group of 20-61 years were involved in this pilot study. Two new parameters, namely the area of the photoplethysmographic waveform under the systolic peak, and the ratio of the time delay between the systolic and the diastolic peaks and the time period of the waveform (ΔT/T) were studied as a function of age. It was found that while the parameter which is supposed to be a marker of distensibility of large arteries and ΔT /T values correlate negatively with age, the area under the systolic peak correlates positively with age. The results suggest that the derived parameters could provide a simple, non-invasive means for studying the changes in the elastic properties of the vascular system as a function of age.

Keywords: vascular compliance, photoplethysmograph, systolic peak, second derivative

1. INTRODUCTION

PHOTOPLETHYSMOGRAM (PPG) expresses changes in the volume of blood in the finger tip, which provides a means of determining properties of the vascular tree during the cardiac cycle and changes with aging and disease. These signals can be easily obtained from the tissue pads of the ears, fingers and toes where there is a high degree of superficial vasculature [1]. Photoplethysmography is a simple and inexpensive optical technique, which is often used non-invasively to make measurements at the skin surface [2] Although the origin of the components of the PPG signal is not fully understood, it is generally accepted that they can provide valuable information about the cardiovascular system [3, 4, 5]. There has been a resurgence of interest in the technique in recent years, driven by the demand for a low-cost, compact, simple and portable technology for the primary care and community-based clinical settings and the advancement of computer-based pulse wave analysis techniques. The PPG technology has been used in a wide range of commercially available medical devices for measuring oxygen saturation, blood pressure and cardiac output, assessing autonomic function and also detecting peripheral vascular disease.

Age-related changes in the pulse shape characteristics can also yield valuable diagnostic information about the cardiovascular system. There has been published data in the literature, which quantify pulse transit timing changes with age [3, 6]. Frequency analysis of the PPG signals at different body sites with respect to age has been carried out [7, 8] and it has been shown that there is a general reduction in the harmonic components of the pulse in older subjects. Work has also been done using the second derivative of the photoplethysmogram (SDPPG) to study age-related indices and other risk factors for atherosclerotic vascular disease [9, 10]. This has proved to be particularly useful when the dicrotic notch in the PPG signal becomes less prominent, making it difficult to detect minute changes in the phase of the inflections using the pulse wave contour itself.

The contour of the pulsatile component of the PPG has been used for the calculation of certain age-related indices like the minimum rise time, stiffness index etc., using the mean pulse function [11, 12, 13]. Here we have attempted to find a parameter which is related to the distensibility of large arteries, using the SDPPG and to correlate the same with age, using the hardware setup developed in our laboratory. We have also arrived at two parameters , which to the best of our knowledge has no published data in the literature, and correlated the same with age. These two parameters, namely the area under the systolic peak and the ratio of the time difference between the systolic and diastolic peaks and the total period of the PPG, seem to have good correlation with age. Such data, and a better understanding of the characteristic features of the pulse, are required if the PPG pulse is to be used as a non-invasive clinical diagnostic tool.

2. PRINCIPLE OF MEASUREMENT

A mean pulse function was derived from the window of resting PPG data and the peaks were located using the derivative of the mean pulse function. The characteristics of the pulse shape for subjects with three different ages are shown in Fig.1.

The contour of the PPG signal exhibits an early systolic peak and a latter peak or point of inflection that occurs a short time (ΔT) after the first peak in early diastole, as shown in Fig.2. The systolic component results from the direct pressure wave travelling from the left ventricle to the digit, and the diastolic component results from reflections of the pressure wave by arteries of the lower body back to the finger. The time difference between these two peaks (ΔT) is a measure of

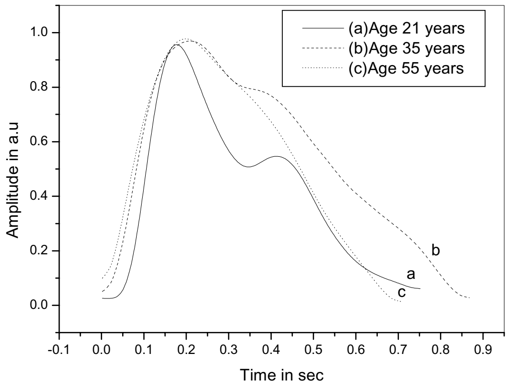

Fig.1 Mean pulse shape for subjects aged 21, 35 and 55 years.

the transit time between the subclavian artery and reflection sites and has been used to define a non-invasive measure of large artery stiffness [15, 16].

The set of measured pulses is optimized for contour similarity in order to minimise the effects of motion and damping artefacts normally present in such data. Also, normalization of the mean pulse function was performed for overall shape assessment and to get rid of variability due to heart rate differences [16]. From this ensemble, averaged mean pulse ΔT was determined as the time between the first systolic peak and the early diastolic peak inflection point in the waveform. The peaks were located using the derivative of the mean pulse function. The systolic peak was identified as the first zero crossing and the subsequent negative zero crossing, or positive inflection nearest to zero determined the time of the diastolic peak or inflection occurrence. It is not necessary that in all the age groups the dicrotic notch be predominantly seen. In these cases the second peak is considered to be the point of inflection itself.

From the recording of the original PPG, sometimes there is a difficulty in detecting minute changes in the phase of the inflections . So, by double differentiating the PPG (SDPPG), a more accurate recognition of the inflection points and an easier interpretation of the original signal are possible.

The SDPPG is used as a means to accentuate and locate inflection points and a specific nomenclature has been adopted, such that the five sequential waves are designated as a, b, c, d, and e. [10]. To describe the SDPPG components quantitatively, the height of each wave was measured from the baseline, the value above the baseline being positive, and those under it negative. The a, b, c, d and e waves represent the initial positive, early negative, re-increasing, late re-decreasing , and diastolic positive waves, respectively. The normalised mean pulse and its second derivative in the case of a 25 year old subject is shown in Fig.2. Absolute values for the height of the waves 'a' & 'b' were referred to as 'A' & 'B', respectively[11].

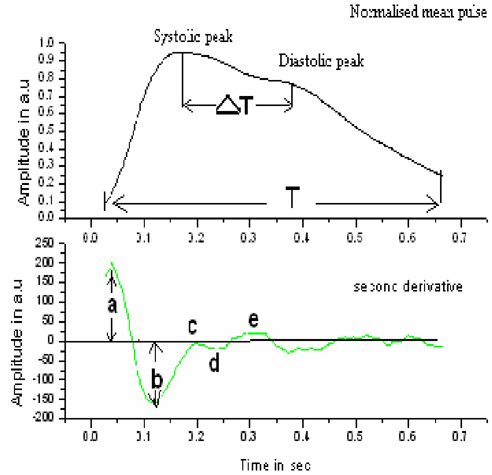

Fig.2 Normalised mean pulse and its second derivative (SDPPG) of a 25 year old subject. The waveform of the SDPPG consists of four systolic waves (a, b, c and d waves) and one diastolic wave (e wave).

3. MATERIALS AND METHODS

3.1 Measurement system

A schematic of the recording system used is shown in Fig. 3. The PPG signals were recorded in the reflection mode with a self-designed probe (Velcro strap) and measurement setup [17]. The source used was a light emitting diode transmitting IR light at 940 nm and a photodiode was used as the detector. The bandwidth of the PPG amplifier was designed to be within 0.5 to 8 Hz, so as to eliminate low frequency baseline fluctuations as well as the high frequency noise. All the signals were recorded using a digital storage oscilloscope Tektronix (TDS5104 B) and the sampling rate used was 500 Hz. All processing and post-processing were performed using MATLAB and Microcal Origin software.

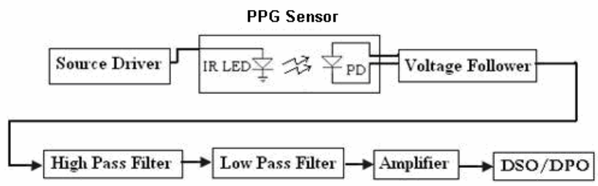

Fig.3 Schematic diagram of the experimental setup.

3.2 Subjects

A total of 30 subjects (14 female, 16 male) were involved in the study, with their ages ranging from 20 to 61 years . The demographic data of the subjects were as shown in Table 1. The inclusion criteria were: no clinically apparent arterial disease or physical abnormality, not observantly obese or on any medication. Each subject was informed about the details of the study and their verbal consent was taken before the recordings were made. Peripheral pulse measurements were recorded for 10 sec with the subject sitting on a chair and the arm positioned at heart level with the forearm resting on a table in a temperature controlled room (24±1.5^{o} C). Care was taken to see that the effect of motion artefact was the lowest possible. The subjects were also asked not to undergo strenuous exercise, avoid consuming hot drinks or those containing caffeine, and refrain from smoking for 2 hours prior to recording. It was also ensured that the subjects were relaxed and breathing regularly and gently.

Parameter	***Mean ± SD***
Age(years)	34.87 ± 11.65
Weight(kg)	55.9 ± 7.844
Height(cm)	161.8 ± 8.343
SBP(mmHg)	108.2 ± 8.4
DBP(mmHg)	76.3 ± 7.4

Table 1 Demographic data of the subjects in this study

3.3 Method

The PPG signals were recorded from the index finger of the right hand as there is evidence that differences between the age groups are more significant for the right hand compared to the left hand. A program was written in MATLAB to determine a mean pulse function from the window of resting PPG data, which was recorded over a period of 10 s. Out of the three indices that we studied, the parameter related to the distensibility of large arteries (B:A ratio) was derived from the SDPPG and the other two parameters, namely the area under the systolic peak and the ratio of the time difference between the systolic and diastolic peaks and the total period of the PPG from the normalised mean pulse of the original PPG.

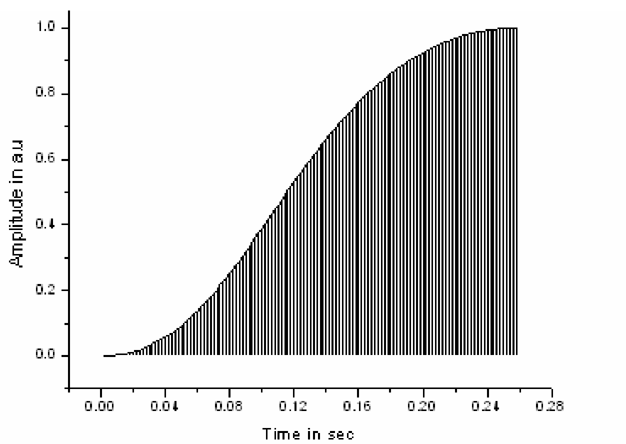

Fig.4 Determination of area under the systolic peak.

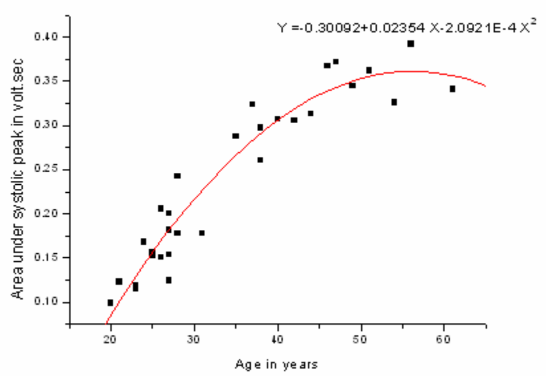

Fig.5 Variation of area under the systolic peak with age.

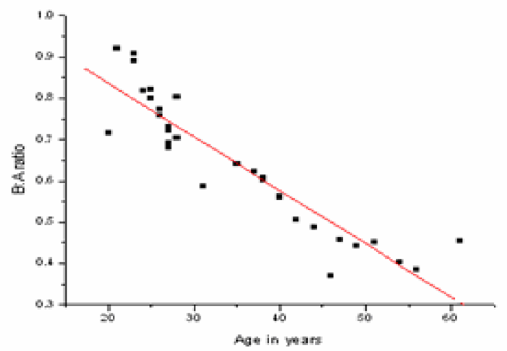

Fig.6 Variation of B:A ratio with age.

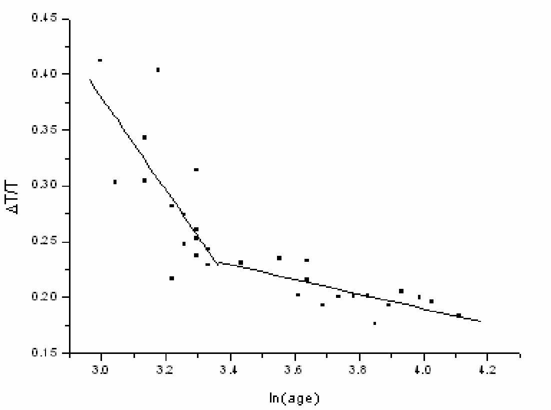

Fig.7 Variation of $\Delta T/T$ with ln(age).

The waveforms were analysed offline using MATLAB and Microcal Origin 7.0. Anomalous pulses due to movement or irregular breathing were eliminated from the analysis. Pulse shapes for normal healthy subjects were analysed. It is clearly seen from Fig.1 that the pulse contour exhibits changes in shape with respect to the systolic slope and the demarcation of the dicrotic notch. The ratio between ΔT & T for differently aged subjects was calculated from the normalised mean pulse. The area under the systolic peak was calculated as the area lying between the foot of the wave and the systolic peak, as shown by the shaded area in Fig.4. Fig.5 and Fig.6

show the variation of the area under the systolic peak, B:A ratio as a function of age, respectively. A plot of ΔT/T vs. natural log of age is shown in Fig.7.

4. Results and discussion

The PPG signals for normal healthy subjects were analysed. In older subjects the dicrotic notch is less pronounced, which could be mainly attributed to age-related increases in pulse wave velocity [6,14]. The increase in pulse wave velocity is due to increased large artery stiffness with age resulting in a faster reflected wave augmenting the forward wave. Hence the value of 'ΔT' is found to decrease as age increases and ΔT/T correlates negatively with age, with the slope for the age group 20 to 28 years being higher when compared to the age group 31 to 61 years. The variation in slope may be attributed to the stiffening of arteries and increase in stiffness index_ with age. Also, in older subjects it is difficult to locate the dicrotic notch, thereby increasing the uncertainty in timing measurements related to the reflected wave. Here, by making use of the SDPPG, delicate changes in the waves were emphasized and easily quantified by differentiating the original PPG signal with respect to time. The B:A ratio could be considered as a marker of distensibility of large arteries, and hence little affected by the reflection wave [18]. The area under the systolic peak is found to increase almost linearly up to the age of 31, and above that there is a slowing down in the rate of increase. The increase in the area under the systolic peak could be attributed to an increase in systolic stress and therefore increased systolic load resulting in part from systemic arterial stiffening. Stiffening of the arterial tree, whether due to aging, diabetes or other cardiovascular risk factors has important haemodynamic consequences and there is a strong correlation between aortic stiffness and the degree of coronary artery disease [19]. All the three parameters that we evaluated were derived from the PPG signals recorded, using the hardware setup indigenously developed in our laboratory.

5. Conclusion

Our analyses showed the overall trend of changes in pulse shape characteristics, with advancing age in a normal study population, using a cost-effective, self-designed hardware setup. In older subjects, the arteries are less distensible, resulting in a lower value of the B:A ratio. The three parameters that we have determined, can provide a simple non-invasive means for studying the changes in the elastic properties of the vascular system. The obtained results demonstrate that the overall effect of changes in arterial properties, such as relating to arterial stiffness, can be detected non-invasively from the finger tip by examining the mean pulse shape and the SDPPG characteristics. The present study is only a preliminary one and it is worth noting that there are some limitations to the present study as a wide range of age could not be covered. Further tests in a clinical environment are necessary, to facilitate in evaluating subjects with hypertension , diabetes, etc. A detailed study with a larger number of subjects is currently under progress.

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