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The Investigating of Photoplethysmogram Waveform Amplitude Changes: Aging and Atherosclerosis

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Abstract

This paper focuses on the analysis of PPG waveform amplitude changes. As PPG signal reflects blood volume changes, studying its (peaks and valleys) amplitudes changes is highly appreciated. The results showed a strong positive relationship between age and RI index (R square = 0.657) and a strongly negative relationship between age and systolic peak index (R square = -0.651). The obtained results underline the importance of studying PPG's (peaks and valleys) amplitude changes and their association with age and atherosclerosis. The association between aging, atherosclerosis, arterial stiffness and PPG's morphology can provide a fruitful tool towards disease prevention and early-risk prediction. The increment of systolic peak as we age might indicate the present of atherosclerosis and the start of arterial stiffness. In addition, the increment of RI index as we age, may contribute to the process of high-risk atherosclerosis prediction and therefore approaching risk prevention.

Keywords: PPG; RI; Systolic Peak; Atherosclerosis; Age.

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1. Introduction

The PPG waveform comprises a pulsatile (AC) physiological waveform attributed to cardiac synchronous changes in the blood volume with each heart beat [1]. PPG measurements were done on the index finger since finger PPG is a commonly used technique in medicine and since it is easier for recording [2-3]. Several studies have emphasized the important information embedded in photoplethysmogram (PPG) waveform for the assessment of arterial stiffness and aging [4]. The use of PPG to study vascular aging, arterial stiffness, atherosclerosis, endothelium dysfunction and erectile dysfunction is highly appreciated [5]. PPG is highly affected by aging which noteworthy to be observed by the variations of PPG contour. Since we advance in age, PPG becomes more rounded which in turn make PPG inflection point and dicrotic notch less pronounced [6]. Arterial stiffness can be measured noninvasively by the use of the PPG technique, which reflects the changes in blood volume with each heartbeat. Perhaps the most exciting application of PPG waveform analysis is the possibility of providing a rapid biophysical measure of diseases or aging process [7]. Figures 1-3 displays a single_pulse PPG waveform, first_derivative PPG waveform, and second_derivative PPG waveform respectively. The use of PPG's signal derivatives is developed to facilitate the accurate recognition of the PPG's points of interest and to ease the interpretation of the original PPG waveform [6].

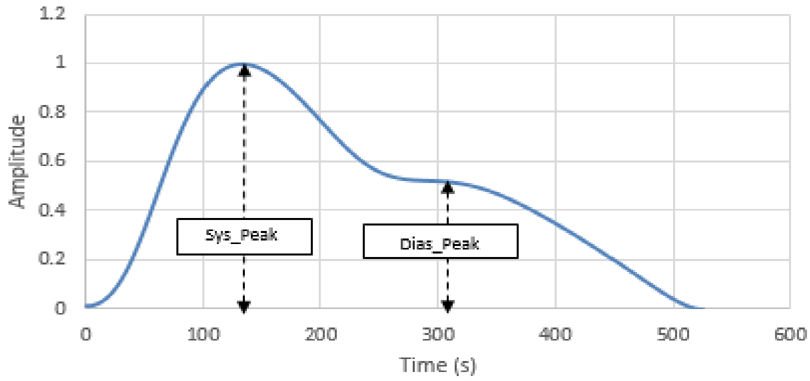

Figure 1: Single_PPG_Pulse_58 Years Old

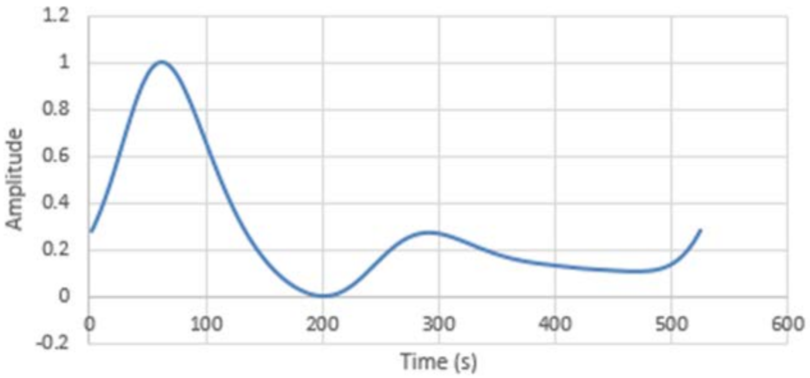

Figure 2: 1st Derivative_Single_PPG_Pulse_58 Years Old

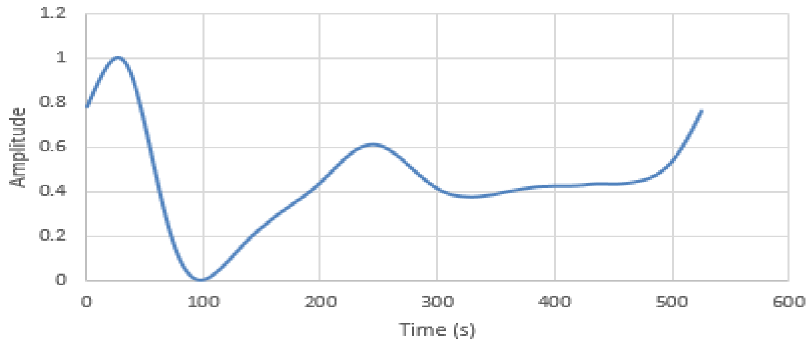

Figure 3: Second_Derivative_PPG_58_Years_Old

2. Methods

A total of 96 participants are enrolled in this study. Their PPG data are collected using a recording system to extract index-finger PPG signals. All subjects are requested not to consume any meal at least 3 hours before the recording. During recording, each participant remains quite and breathes normally. Data are preprocessed, digitize the signals locally, and transmit the digital data to a computer with a sampling rate of 5500 Hz and amplitude of ±6 V. PPG probes functioned on a transmission type sensor while patient is resting in a supine position. Each patient is informed about the study and their written consent is taken before the recordings are made. Subjects are chosen from Zulfi general Hospital and from college of science in Zulfi, Riyadh-KSA. Their data are recorded in a clinical environment (Hospital room ±25). The measurement ran for 90 seconds to ensure the selection of good PPG pulses. The customized algorithm is implemented using (MathWorks MATLAB R2013a). In addition, all statistics are produced using MATLAB and SPSS statistical package. Table 1 below illustrates the descriptive analysis of the collected data.

Table 1: Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Age	96	19.00	72.00	35.4271	15.06459
SyPeak	96	4.00	22.50	13.1542	4.36840
DiPeak	96	.33	.93	.6864	.15687
RI	96	.30	.90	.6218	.13259
Valid N (listwise)	96				

3. Results and discussions

The obtained results showed that PPG's RI index and PPG's Systolic_Peak index are statistically significant in relation to age. As elaborated in table 2, both RI index and Systolic_Peak index showed a p value of less than 0.05%. While the rest of indices are not statistically significant (Diastolic amplitude and incisura amplitude). These results strengthen the association between PPG waveform and aging. However, PPG's RI index showed a positive association with age (the more the RI is, the more the age is), while PPG'S Systolic_Peak index showed a negative association with age (The more the age is, the less the value of Systolic_Peak index). The obtained results indicate the association between arterial stiffness and aging, which in turn can be used as a tool towards the assessment of arterial stiffness and atherosclerosis. The box-plot of PPG's RI index based on different age groups is shown in Figure 4.

Table 2: Bivariate Correlations (Pearson Correlation)

		Age	SyPeak	DiPeak	RI
Age	Pearson Correlation	1	-.651**	.071	.657**
	Sig. (2-tailed)		.000	.495	.000
	N	96	96	96	96
SyPeak	Pearson Correlation	-.651**	1	-.269**	-.508**
	Sig. (2-tailed)	.000		.008	.000
	N	96	96	96	96
DiPeak	Pearson Correlation	.071	-.269**	1	.117
	Sig. (2-tailed)	.495	.008		.256
	N	96	96	96	96
RI	Pearson Correlation	.657**	-.508**	.117	1
	Sig. (2-tailed)	.000	.000	.256	
	N	96	96	96	96

**Correlation is significant at the 0.01 level (2-tailed).

3.1 PPG reflection index

Reflection index (RI) is derived as a ratio of pulse inflection peak amplitude (second peak) over the pulse max amplitude (first peak). Figure 4 shows the box plot of RI based on several age groups, while figure 5 demonstrates the scatter plot of RI index and aging. RI can provide a window to vascular age and arterial compliance. RI mainly depends on the detection of PPG second peak which tends to be less pronounced with aging [8]. RI may provide a window to small and medium arteries compliance and it can be a measure of small and medium arteries stiffness [6]. Reflection index is calculated based on equation 1:

$$RI = \frac{Dias_{peak}}{Sys_{Peak}} * 100\% \dots\dots\dots\dots\dots\dots.(1)$$

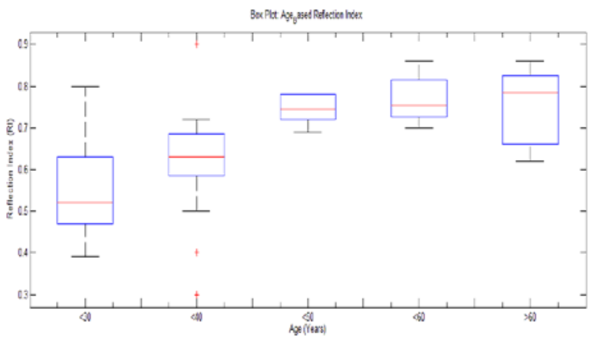

Figure 4: PPG's RI index association with different age groups.

Figure 5: Scatter plot of Age vs. RI index

As shown in figure4 and figure 5 above, RI index is highly associated with age. The box plot demonstrates how RI index tends to be increased as we age. The scatter plot in figure 5 underlines the positive correlation between age and RI index. The interpretation of these results describes that PPG's RI is increasing as we get older. This phenomenon supports the saying about diastolic peak to be closer to systolic peak as we age. The rapprochement between systolic peak and diastolic peak can be seen clearly in many rounded PPG waveforms and/ or on many less pronounced dicrotic (incisura) notch peak. This is just a reflection of arterial stiffness.

3.2 PPG systolic peak

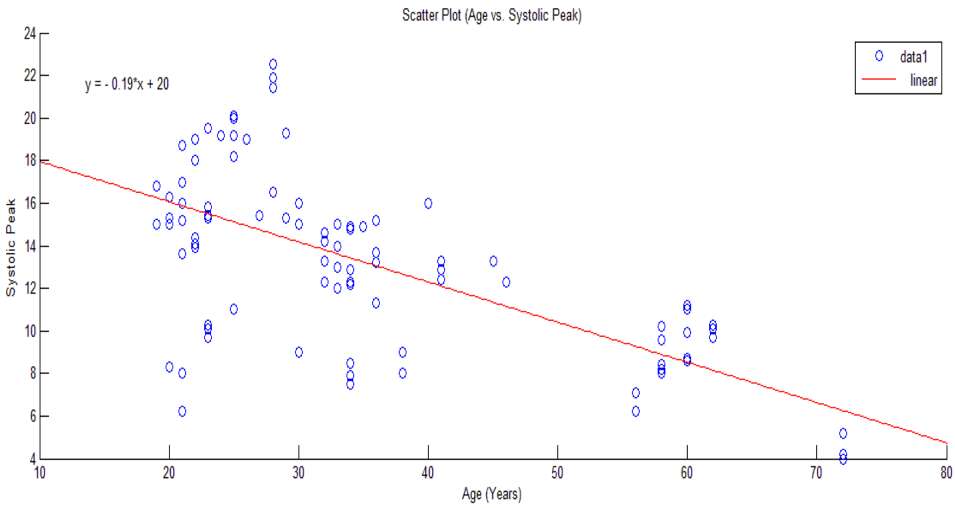

Figure 6: Scatter plot of Age vs. systolic peak index

Systolic_Peak (Amplitude) is an indicator of the pulsatile changes in blood volume caused by arterial blood flow around the measurement site [9-10]. Systolic amplitude has been related to stroke volume [11]. In addition, it found to be directly proportional to local vascular distensibility over a remarkably wide range of cardiac output [12]. Healthy artery shall be low in resistance which in turn increases the compliance, while aging artery is high in resistance which decreases the compliance. Thereby, PM can be used as a measure of arterial compliance since it is going to be reduced with age [8]. Figure 6 below describes the scatter plot diagram for systolic peak index with age.

The exploration of the above diagram shows that there is a negative relationship between age and PPG's systolic peak. This can be used to develop a PPG-based aging index. The effects of aging on PPG's morphology seem to decrease its amplitude due to the increment of arterial stiffness. The results indicate that as we age, the value of PPG's systolic peak tends to decrease. We found this explanation plausible, since arterial endothelial wall tends to stiffen with age which in turns increases the resistance of arterial wall. However, elastic arteries tend to absorb blood pressure since it is flexible. Once arteries become stiffen, their elasticity will be reducing which increase the resistance of arterial wall to dilate.

3.3 PPG diastolic peak

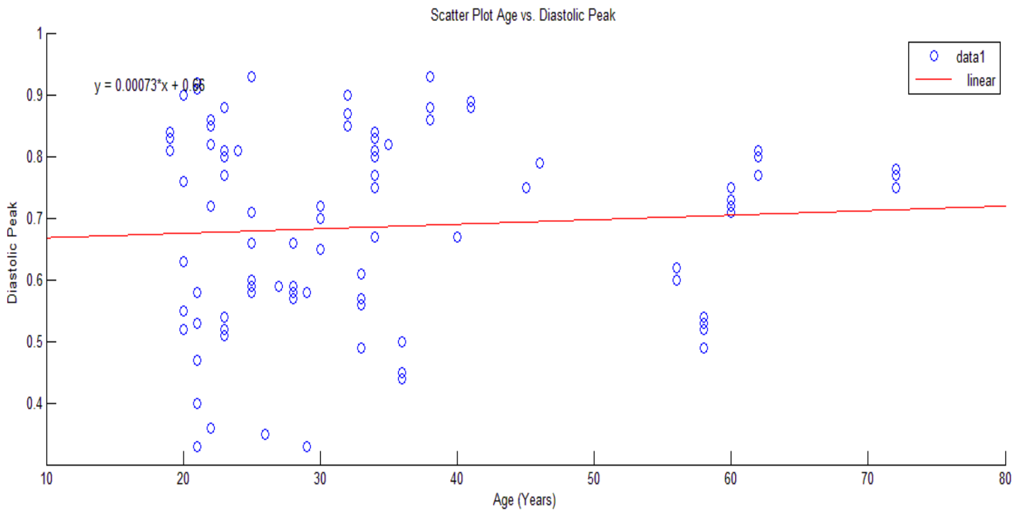

Figure 7: Scatter plot age vs. diastolic peak index

The peripheral pulse wave at the finger characteristically exhibits a systolic peak resulting from the direct pressure wave traveling from the left ventricle to the digit, and a diastolic peak or inflection resulting from reflections of the pressure wave by arteries of the lower body back to the finger [13]. During age advance, diastolic peak tends to be closer to systolic peak [8]. Even though, the obtained results showed, statistically, no significant association between age and diastolic peak amplitude, the relation was positively correlated. As shown in figure 7, diastolic peak amplitude tends to increase with age. Still, to fully approach the elaborating of the association between age and diastolic peak, extra PPG data needs to be conducted and analyzed. Moreover, different age groups and races (especially females) need to be called for recordings.

4. Conclusions

This paper focuses on the analysis of PPG waveform amplitude changes. As PPG signal reflects blood volume changes, studying its (peaks and valleys) amplitudes changes is highly appreciated. When small and medium arteries start stiffening, early detection of atherosclerosis in sub-clinical settings can be investigated and detected. The association between aging, atherosclerosis, arterial stiffness and PPG's morphology can provide a fruitful tool towards disease prevention and early-risk prediction. The results of this work showed that RI index and systolic_peak index are highly associated with age. The increment of systolic peak as we age might indicate the present of atherosclerosis and the start of arterial stiffness. In addition, the increment of RI index as we age, may contribute to the process of high-risk atherosclerosis prediction and therefore approaching risk prevention.

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