The Significance Change of PPG Reflection Index in Left Ventricular Hypertrophy Risk Individual

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Abstract— This paper describes the significance of the Reflection Index (RI) calculated from the Photoplethysmography (PPG) signals of Left Ventricular Hypertrophy (LVH) risk group. A Dolphin One PPG system has been used in this work. During data acquisition, PPG signals have been recorded from the right index finger of two groups of subjects comprising of healthy and LVH risk subjects. The recording of PPG signal follows a custom protocol. The PPG signals obtained were analysed offline using a custom MATLAB algorithm (Math Work Inc) and SPSS version 11.5. The analysis result comparing between the risk and healthy groups shows that the reflection index (RI) is significantly different between the two groups (p = 0.03). Therefore, PPG parameter, RI may be used to characterize LVH syndrome.

Index Terms— Cardiovascular Heart Disease (CHD), Cardiovascular Disease (CVD), Left Ventricular Hypertrophy (LVH), Metabolic Syndrome (MetS), Photoplethysmography (PPG), Reflection Index (RI).

1 Introduction

According to the study conducted by a group of researcher from Institute for Medical Research, population in Malaysia has high prevalence of Metabolic Syndrome (MetS) as compared to other Asian [1]. The MetS may increase the risk for getting Cardiovascular Heart Disease (CHD) and Cardiovascular Vascular Disease (CVD) [2]. LVH is cardiovascular disease associated with the MetS [3]. This disease is normally developed gradually in silent. There are no signs and symptoms can be detected at the early stages of the diseases development, unless they progress [4]. As symptoms of these diseases appeared, usually the diagnosis of LVH can be made by echocardiograph or electrocardiography (ECG), magnetic resonance imaging (MRI) and computed tomography (CT) [4]. However, all of them abide by the complex procedure and the cost constraint. It is probably premature to recommend routine serial of any of the methods as common screening test.

An alternative solution for that scenario has been the topic of interest. In this study, PPG is the main component. It is simple, cheap and non invasive. PPG is a device which can measure blood volume changes in blood vessels from the formed pulse pressure every time the heart beats. The data represented in PPG waveform carries valuable cardiovascular information to be discovered by the researchers for the best of mankind [5].

LVH causes the wall muscle of the left ventricle to thickened and stiffened. As the respective heart muscle weakened, the chamber is prevented from filling with blood properly while the pressure in the heart is elevated. Insufficient blood pumped by the respective heart chamber will results in many other complications [4].

The blood volume is the total of blood in the body. In a normal human body, the blood volume is distributed approximately 88% in the systemic circulation and 12% in pulmonary circulation. The conditions such as left-sided heart failure and mitral stenosis can greatly increase the pulmonary blood volume while decreasing the systemic volume.

The PPG waveform was found to carry significant data on the blood volume changes for the risk subjects using RI calculation.

2 Reflection Index

In the study conducted by Philip J.Chowienczyk, first derivative is used to view the changes in the PPG wave reflection. Fig. 1 defines the parameters for the calculation of RI. Notch or point of the inflection in the PPG pulse of Type II Diabetes Mellitus patients was recorded and measured before and after endothelium-dependent vasodilators were administrated systemically. The notch or the point of the inflection (b) in the PPG pulse is determined by the local maximum in the first derivative wave after the first peak. The height of the inflection point (IP_{DVP}) is expressed as percent of the height of the point (b) and the amplitude of the PPG pulse (a) as shown in (1). The IP_{DVP} is influenced by the pulse wave reflection.

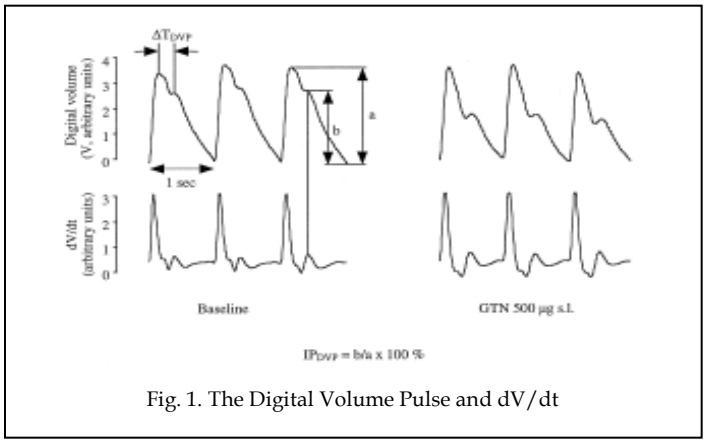

Fig. 1. The Digital Volume Pulse and dV/dt

$$IP_{DVP} = b/a \times 100\%. \quad (1)$$

Millasseau determines the PPG pulse shape taken from the subject's finger by using large artery stiffness index and reflection index. These two features carry cardiac information on the degree of arterial stiffness and vascular tone. To calculate the stiffness index, the amplitude of the pulse is divided by the time delay between the pulse systolic peak and the inflection point of the reflection wave in unit m/s. While, the reflection index is the percentage ratio of the height of the diastolic notch to the peak pulse height.

A normal PPG pulse contains of notch or inflection point in its down slope. It is corresponding to the reflection of blood flow as it hit the wall of elastic arteries of healthy people in each heart beat. The notch or the inflection index is commonly diminishing in the PPG pulse of those who are unhealthy.

3 METHODS

A. Subjects

The study has been approved by the Research & Ethics Committee of Pusat Perubatan Universiti Kebangsaan Malaysia (PPUKM). Thirty healthy subjects (F/M = 25/5) aged 47.1 ± 6.9 (range 33-60) years and thirty risk subjects (F/M = 13/28) aged 50.8 ± 13 (range 23-65) years were involved in this study. The initial criteria of the study subjects were based on the definition of Metabolic Syndrome in IDF 2009 [9]. These criteria were identified at the early stage by Dr S.H.Ahmadshah (PPUKM) through their laboratory results, Echocardiography and ECG. This study will also consider all subjects under treatment or on medication for the stated criteria. The study subjects have or used to have the criteria described in Table 1.

TABLE 1
IDF DEFINITION FOR METABOLIC SYNCROME

1	Waist circumference • Male≥ 90cm and Female ≥ 80cm
2	Plus any two or more criteria below: • TG >1.7mmol/L • HDL = Male< 1.03mmol/L and Female<1.29mmol/L • BP > 130/80mmHg • FBS>5.6mmol/L

The control group consists of healthy males and females who are free from the CVD of age matched to the study group as described above.

B. PPG Experimental Protocol

A single channel PPG system from Dolphin Medical Inc. was used to record the signals from the patient and normal in supine position from the right index finger. The duration of recording is about 3 minutes. The output of the PPG sensor is digitally sampled at 275Hz. The PPG raw data was then stored in .trz file for further analysis using MATLAB (Math Works Inc). From the entire color spectrum, red LED (660nm) is chosen as it offers distinct different between Hb and HbO and produced less noisy signal.

The protocols for PPG data acquisition are set as follows:

1. Measurement must be conducted in the quiet and controlled room temperature (20°C-25°C).
2. Subjects must be at rest, in supine position, breath regularly and minimize movement during the assessment.
3. PPG Finger Clip was mounted to an index finger on the right arm and was measured for about 3 minutes

4 ANALYSIS

The MATLAB (The Mathworks,Inc), Microsoft Office Excel 2003 and SPSS 11.5 for Windows (SPSS Inc.) were performed in this study for analysis.

A. PPG Signal Analysis

In this study, first derivative has been applied to the PPG waveform using custom MATLAB algorithm to identify the notch or the point of the inflection. The notch or the point of the inflection (b1) in the PPG pulse is determined by the local maximum (b2) in the first derivative wave after the first peak. The height of the inflection point (IP_{DVP}) is expressed as percent of the height of the point (b) and the amplitude of the PPG pulse (a) [7].

Fig. 2 shows the PPG signal (dotted line) and its gradient (continuous line) on the separate panels. Fig. 3 consists of the PPG signal and its respective gradient. They have been displayed on the same panel for the ease of calculation.

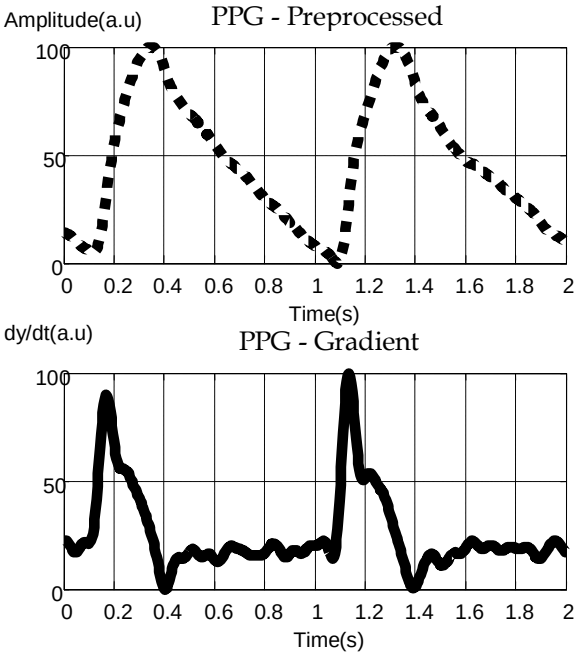

Fig.2. PPG processeed and gradient on separated panels

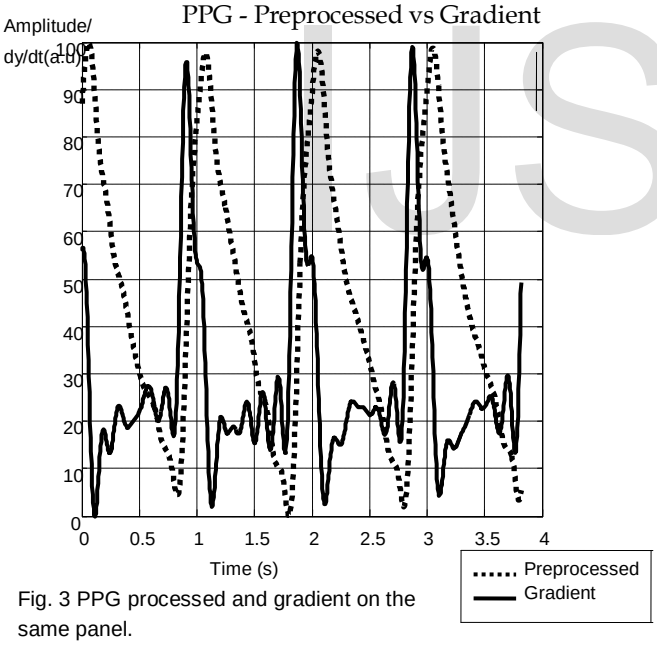

Fig. 3 PPG processed and gradient on the same panel.

The coordinates (x,y) of local maxima from three consecutive PPG gradient pulses were recorded as shown in Fig 4, 5 and 6. These local maxima are corresponding to the notch or the inflection point in the initial PPG signal which designated as (b2). The statistical values for both groups are shown in Table 2.

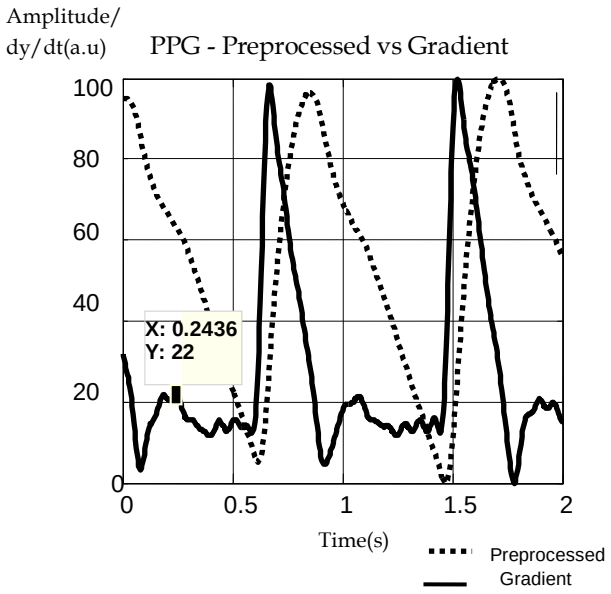

Fig. 4. First coordinate (b2_1)

The actual notch or the inflection point (b1) in the initial PPG signal was determined from the corresponding (b2) coordinates in the gradient pulse. As (b1) and the amplitude of the initial PPG signal (a) were identified, the index of the reflection can be calculated as shown in the Table 2. The RI values studied were averaged of the reflection index from the three consecutives PPG pulses was considered for this research.

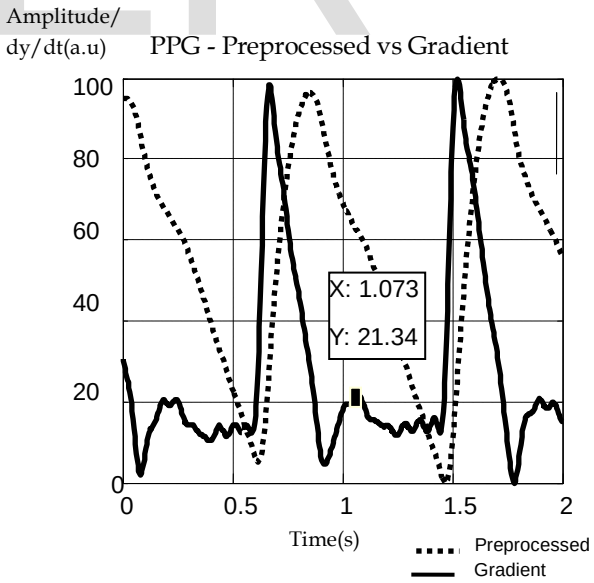

Fig. 5 Second Coordinate (b2_2)

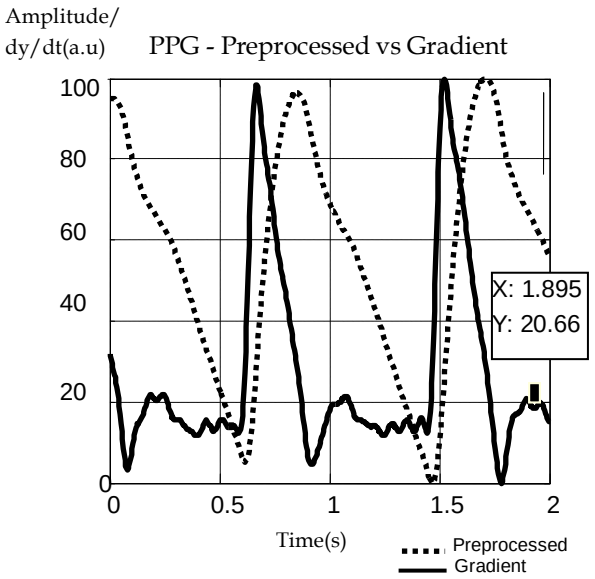

Fig 6. Third Coordinate (b2_3)

TABLE 2
SAMPLE CALCULATION OF REFLECTION INDEX

	PREPRO (a1)	TIME (x_b2)	GRAD (y_b2)	PREPRO (b1)	RI (b1/a1)*100%
1	94.99	0.244	22	63.16	66.49
2	96.34	1.073	21.34	61.73	64.08
3	100	1.895	20.66	67.75	67.75
Mean *(SUM /3)*	97		21.33	64.213	66.2

B. Statistical Analysis

The statistical analysis was performed using SPSS 11.5 to evaluate the significant trends on the PPG data. The Independent Sample Test was performed to compare the RI significant difference between the control and study groups. The test was two-tailed and the significant level was set at $P < 0.05$.

5 RESULT AND DISCUSSION

The general pattern in the PPG waveform is formed as a result of the complex interaction between the left ventricle and the peripheral vessel in systemic circulation.

In PPG waveform, this first peak is known as an early systolic peak and later in early diastole is a point of inflection. The first peak is corresponding to the pressure transmitted along blood vessels from the left ventricle to the finger. While, the second peak is formed by the pressure transmitted along the aorta and large arteries to sites of impedance mismatch in the lower body, where it is back up the aorta and to the finger [8].

The RI is a measurement of the amount pulse wave reflection which is correlated to the small to medium sized arteries stiffness and tone. The previous researchers had defined the reflective index as to representing the diastolic component of the digital pulse wave [10].

Table 3 contains of the value of RI for healthy female and male subjects obtained in the research study by Divina G.Brillante.These data can be used for references and comparison purposes.

TABLE 3
RI (%) OF HEALTHY VOLUNTEERS (NON-CAUCASIAN)

Age (years)	RI (%)		
	Overall	Female	Male
18 - 34	73 ± 15	72 ± 15	69 ± 16
35 – 49	76 ± 9	76 ± 8	76 ± 9
50 - 67	83 ± 10	79 ± 7	82 ± 7

Source: (Divina G. Brillante 2008)

However, due to imbalance number of female and male subjects in this study, only overall percentage had been considered in both groups.

Table 4 represents RI (%) for control group of this study. The data for aged range 18-34 years old does not available due to insufficient number of the subject. The values obtained for other range of age were relatively similar to that in Table 3.

TABLE 4
RI (%) OF CONTROL SUBJECTS

Age (years)	RI%
18-34	0
35-49	78.361±8.248
50-67	83.523±8.277

Table 5 represents RI (%) for the study group. There was significant difference between these two groups. The value for each range was literally smaller than the control group but the standard deviations were high in each group.

TABLE5
RI (%) OF STUDY SUBJECTS

Age (years)	RI%
18-34	63.903± 17.817
35-49	69.295±15.445
50-67	78.103±8.514

Table 6 shows the evaluated parameter for the control and the study groups. In the t-test, P-value for the equality of means is 0.03. The RI of the study group is significantly different from the control group.

TABLE 6
STATISTICAL PARAMETERS FOR THE RI

	Unit	Control group (N = 30)		Study group (N = 30)		t-test
		Mean	SD	Mean	SD	P value
Reflection Index (RI)	a.u	80.55	8.37	74.27	12.53	0.03

Fig. 7 and Fig. 8 show the Error Bar plot and Box plot of the RI, respectively, of the control and study group. It is shown that the reflection index in the study group had high standard deviation (SD). The RI had varies from low to high value as the subjects had different medical background and the MetS criteria.

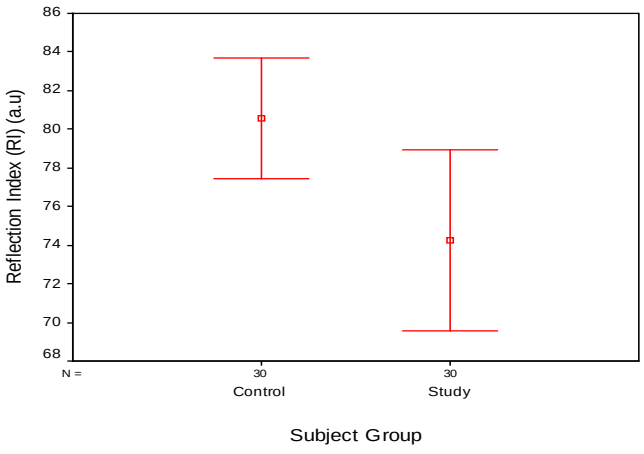

Fig. 7 Error Bar Plots of Reflection Index

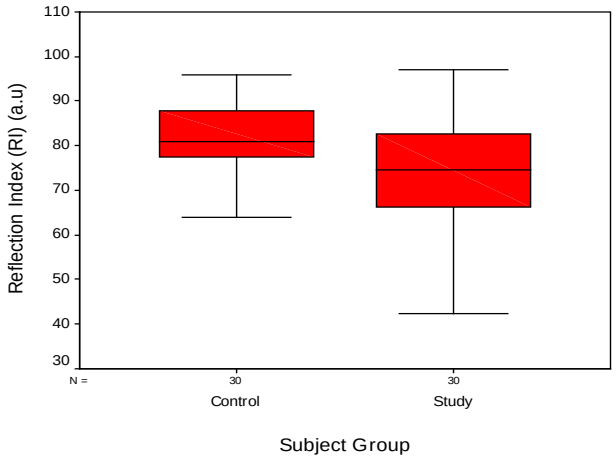

Fig. 8: Boxplots of Reflection Index

6 CONCLUSION

The digital pulse wave initially contains information on the peripheral pressure pulse. Hence, many studies had discovered the correlations of the digital pulse wave information with the risks of the cardiovascular events [10]. At present, most of the PPG studies in medical field are interested on the changes, responses and the effects on peripheral circulation or the blood arteries. This study has shown the complex relationship of PPG signal and the heart status. The RI of these PPG signals carry data on the LVH signs. It is another PPG capability to discover valuable cardiovascular information [5]. The criteria of MetS in one person can be different from an individual to another [9].This study can be further improved by having study subjects with the similar medical background and specific MetS criteria.

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