

Photoplethysmography Signal in Paroxysmal and Persistence Atrial Fibrillation Patients

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Abstract: Atrial Fibrillation (AF) is one of the most challenging heart ailments to be detected due to its nature being intermittent in early stage of its presence. The challenges become greater when early detection found to be the best treatment method. Currently, guidelines for the early detection and treatment of occult AF are limited. Electrophysiology study is most reliable noninvasive screening method used in AF detection. Electrocardiogram (ECG) is the present electrophysiological measurement in clinical practice. In this study, Photoplethysmogram (PPG) based physiological measurement is introduced through heart rate variability and cardiac cycle fitness as the potential AF screening index. Seven subjects, one normal and six clinically confirmed AF patient's PPG were recorded. All patient's blood profile (INR and blood glucose) and blood pressure measurement were retrieved from pass clinical record. Infographic and data visualization technique were adopted in presenting the AF presence in PPG signal. This preliminary result has provided a foundation for AF detection by using PPG waveforms. PPG is known for its simplicity in terms of cost and utility which able to provide an opportunity to be introduced as home-based AF monitoring tool.

Key words: Photoplethysmography, atrial Fibrillation, paroxysmal, persistence, international normalized ratio

INTRODUCTION

The existence of Atrial Fibrillation (AF) or known as cardiac arrhythmias in adults increases with age. The global prevalence rate is estimated to be 5% for those who are over then 60 years old while 10% for people over 80 years old (Liang *et al.*, 2012). AF increases the mortality rate, the risk of stroke and the heart attacks among sufferers. It occurs when irregular heartbeats happen at atria and produce rapid cardiac muscle contraction with unsynchronized rhythms. AF risk is also found with other factors such as hypertension or High Blood Pressure (HPN), Diabetes (DM), Coronary Artery Disease (CAD), Ischemic Heart Disease (IHD), atrial flutter, thyroid disease, heavy smoker, excessive alcohol and others (Cohen *et al.*, 2010).

There are 3 types of AF in clinical definition that is paroxysmal, persistence and permanent AF. Each of them leads to different diagnosis needs; Paroxysmal AF: or AF occurs sometimes, stops by itself and heart return to normal rhythms. It may last for few minutes, hours or days. Persistence AF: AF does not stop on its own but will need to be treated by medication of electrical

shocks. Otherwise the heart will not be able to return to normal rhythms. Permanent AF: AF that cannot be corrected. At this stage the only invasive device can help the heart to return to normal rhythm. To control the occurrence of AF, one of the effective and safe drugs commonly used is warfarin (Keeling *et al.*, 2011). It is anticoagulant drugs that are often prescribed for subjects who have a condition caused by a blood clot (Giugliano *et al.*, 2013). Warfarin has become one of the anticoagulant treatment to regulate also reduce from bleeding and clotting in veins or arteries.

This drug works well to prevent stroke, however the use of warfarin also raises the risk of bleeding (Rice *et al.*, 2003). Subjects taking warfarin need regular blood tests to monitor the International Normalized Ratio (INR) level shown with range in Table 1. This study focuses on analysis of the relationship of PPG morphology and the level of INR from blood test which categorizes the AF type for healthy and AF subject.

A Photo Plethysmo Gram (PPG) is a noninvasive circulatory signal related to the blood volume change in tissue and collected by optical sensors. It has potential to be used in vascular physiological condition

Table 1: The INR level with range for AF subject

INR level	INR target (range)
<2.0	Normal sinus rhythm
2.0-3.0	Atrial fibrillation (acute) Prior embolism
>3.0	Left atrial thrombus AF plus systemic Embolism (chronic) Left atrial thrombus

Table 2: Summary of technique review for heart rate and cardiac cycle in PPG

Researchers (year)	Techniques	
	Heart rate	Cardiac cycle
Fu <i>et al.</i> (2008)	Wavelet multi-resolution analysis	-
PS and Jatti (2015)	Wavelet decomposition (daubechies)	-
Chang and Chang (2009)	Traditional maximum peak (MP)	-
Jayadevappa and Holi (2016)	-	Computer-based pulse wave analysis
Sahoo and Rath (2012)	Discrete wavelet transform	Discrete wavelet transform

monitoring. PPG has been recommended in preliminary screening by using its derivation such as heart rate, respiration rate and blood oxygen saturation. The sensor consists of a photo detector with light emitting diodes that have two different wavelengths: red at 660 nm wavelengths, infrared at 960 nm wavelength. In this study, we are focusing on the red light since it is found to be of the most resonant to the human cell and skin surface (Elgendi *et al.*, 2013). PPG signals are composed of AC and DC which represent pulsatile and non-pulsatile component, respectively. AC component is synchronized with the pulsation of the heart and related to atrial pulsation but DC has been referred to light absorption in the tissue, represents diastolic atrial blood volume and vein properties (Bagha and Shaw, 2011). Past researches recommended AC component for heart study and health monitoring activities. Heart rate and cardiac cycle are the two common PPG parameters used in cardiovascular health monitoring (Zahedi *et al.*, 2008). Table 2 is a summary of heart rate and cardiac cycle fitness derivation from PPG signals through different techniques. Heart Rate (HR) is calculated based on the total number of pulses for a specific time multiplied by one minute duration as in Eq. 1:

$$HR = \frac{\text{No. of pulses}}{\text{Duration (sec)}} \times \frac{60 \text{ sec}}{1 \text{ min}} \quad (1)$$

Figure 1 is a PPG waveform of a healthy subject with 8 pulses of signal. Heart rate is the total number of pulses in one minute and cardiac cycle fitness in PPG represented

by one pulse as in Fig. 1b. Electro Cardio Gram (ECG) is the gold standard physiological signal used in heart related screening and diagnosis in clinical setting. One cardiac cycle is represented by PQRST peaks in ECG signal which comprises the atrial systole and atrial diastole which indirectly reflect ventricular systole and ventricular diastole activity (Conen *et al.*, 2009) as in Fig. 2. The R-R interval is one of ECG parameter that has been established for AF detection. In this study, we are proposing to use two properties of PPG for early screening of AF presentation. Heart rate variability and cardiac cycle fitness are the two identified parameters which has the similar properties with ECG R-R interval and cardiac cycle fitness.

MATERIALS AND METHODS

Clinically diagnosed six AF patient's from INR Clinic 2 which operates once weekly (every Tuesday) at Pusat Perubatan Universiti Kebangsaan Malaysia (PPUKM), Cheras, Malaysia were recruited for this study. One healthy subject was included to establish the baseline for the study. The subjects were recorded in sitting position with the PPG sensor was placed at the index finger. The duration of the PPG signal recording was 90 sec with total subject engagement time of about 10 min for data acquisition shown in the flowchart in Fig. 3.

The overall data acquisition from the subjects consisted of three parts: part recording PPG signal, part interview session using questionnaires and part collecting the demographic data in medical and laboratory from the patients records based on MRN number from the subject file (Rich, 2009).

Patient screening criteria: In this study, we are focusing on the INR level as a detection mechanism for AF condition among the subjects. Referring to Table 2, the normal sinus rhythm or healthy subject with INR level is below 2.0. INR target range is between 2.0-3.0 indicates acute AF or prior embolism that contains 3 types of AF that is paroxysmal, persistence and permanent AF, while INR above 3.0 is high that indicates chronic AF plus systemic embolism. High INR can increase risk of bleeding (Tran *et al.*, 2013).

Photoplethysmogram recording: During data acquisition the subject are advised to stay calm and relax throughout the recording. Data recording in resting condition is important to obtain stable PPG signals (Fu *et al.*, 2008). The recorded PPG signal was preprocessed and presented using Infographic and data visualization techniques for further analysis using MATLAB.

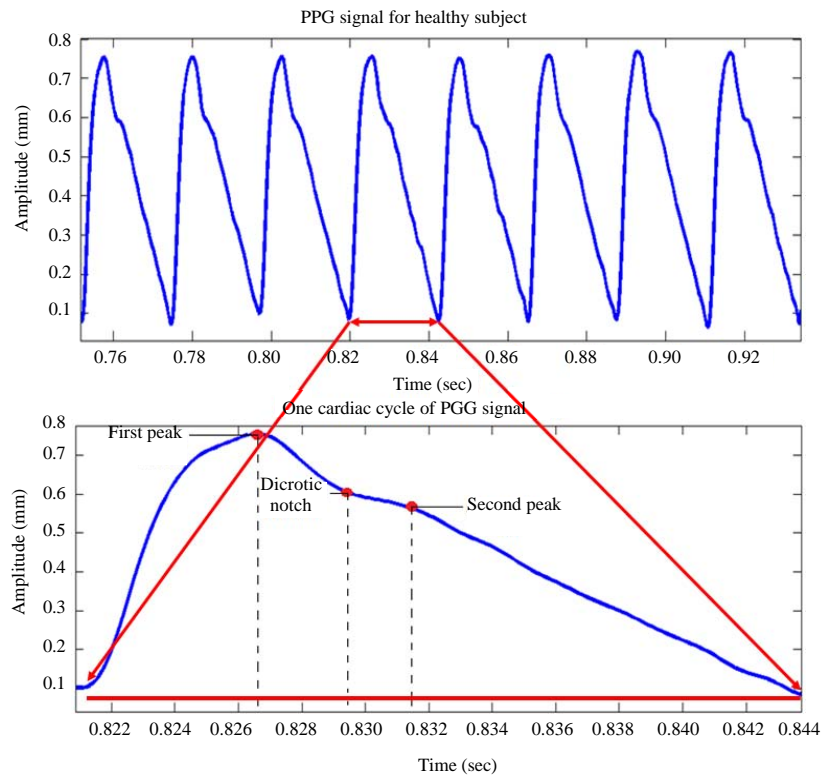


Fig. 1: Healthy PPG waveform: a) 8 pulses and b) 1 PPG pulse

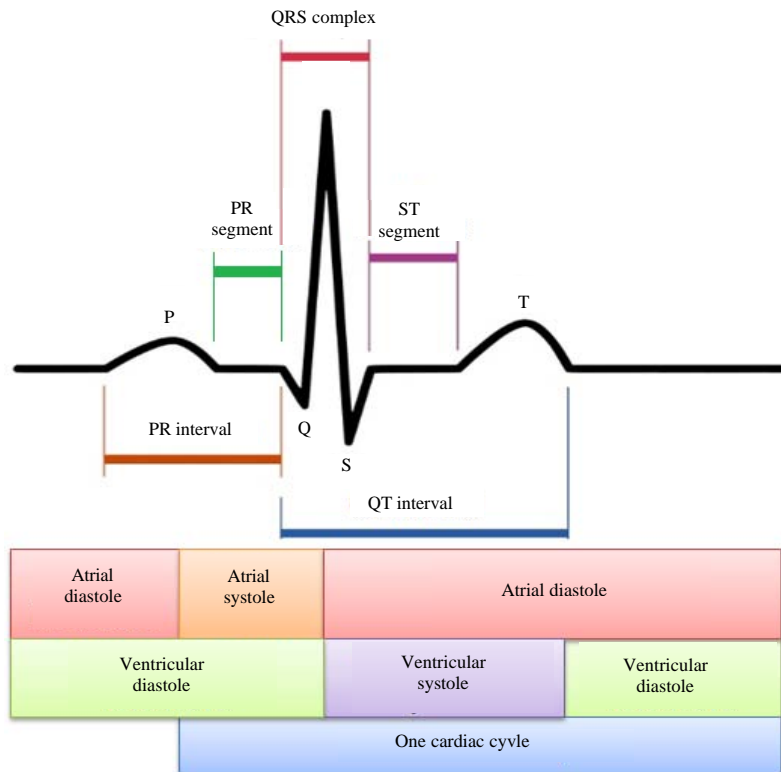


Fig. 2: One cardiac cycle ECG properties

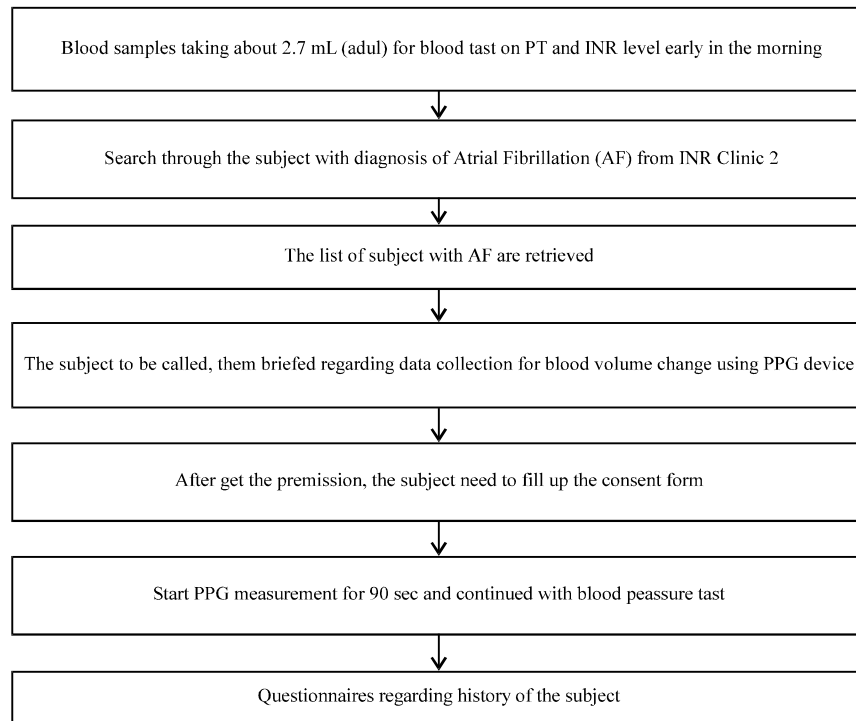


Fig. 3: Flowchart of data acquisition for AF subjects

RESULTS AND DISCUSSION

In this study, we present the analysis data of a control (healthy) subject and subjects with acute AF condition (3 subjects with paroxysmal AF and 3 subjects with persistence AF). These subjects have been chosen based on the INR level from their blood test as shown in Table 3 which also shows the subjects demographic data. Subject S005 is a healthy person without AF and the other 6 subjects are of AF patients. Full information regarding the AF subjects include information of the age, gender, blood pressure, different blood test and types of others diseases. Subject S015, S019 and S035 have the paroxysmal AF while subjects S001, S002 and S006 have the persistence AF. The demographic data in Table 3 shows the Blood Pressure (BP) comprises 4 basic measurements that is systolic BP, diastolic BP, pulse pressure and heart rate. Blood test result contains several results that are listed such as INR level, Prothrombin Time (PT), average blood sugar level (HbA1c) and Fasting Blood Sugar (FBS) but in this study we only focus on reporting the INR level. Based on the diseases listed all AF subjects have Hypertension (HPN), Diabetes Mellitus (DM) which also include other diseases that are related to AF such as atrial flutter, hyperlipidemia and bronchial asthma. Table 3 is useful especially to obtain the health

condition of the subjects with certain information that is important in detection of AF after capturing the PPG signal. As compared with healthy (control) subject in Fig. 1, the PPG pulses clearly shows the first peak (systolic) and second peak (diastolic) in one cardiac cycle properties. In this healthy signal, each of the cardiac cycle have a similarity properties with almost all of the pulses are having the same amplitude and the time between pulses are almost the same indicating similar pulses width. The healthy subject's PPG signal will be a reference to be compared with the PPG signal of the AF subjects in this study.

Figure 4 shows three PPG signals with paroxysmal AF that is in early detection on AF condition. This entire signal shows repeated event on AF signal based on different amplitudes and pulse width which occurs occasionally. The boxes in the figures highlight by red boxes the PPG pulses irregularities in terms of pulse amplitude and pulse width. In these subjects, based on PPG waveform irregularities, the event of AF can be counted. The subjects are taking medication that is warfarin to control the blood flow.

Meanwhile in Fig. 5 the PPG signals for three subjects with persistence AF are irregular where inconsistencies in terms of amplitude and pulse width can be seen quite obviously. The subjects are being treated

Table 3: Subject demographic data of healthy and AF subjects

Sub. No.	Blood pressure						Blood test				Disease
	Age	Gender	Sys.	Dias.	P.P	HR	PT	INR	HbA1c	FBS	
S005	60	M	123	97	26	89	23.4	2.15	5.2	4.83	Without AF
S015	63	F	129	98	31	92	23.4	2.15	16.1	22.82	Paroxysmal, HPN, DM
S019	65	F	140	91	49	75	30.0	2.95	5.6	4.73	Paroxysmal, HPN, DM
S035	59	F	129	73	56	66	23.6	2.17	5.0	5.03	Paroxysmal, HPN, DM
S001	67	M	157	120	37	97	23.2	2.13	5.4	5.61	Persistence, HPN, Atrial Flutter, Hyperlipidermia
S002	59	M	137	90	47	90	24.5	2.28	6.6	6.49	Persistence, HPN, T2DM, Atrial Flutter, Bronchial Asthma
S006	65	F	150	100	50	93	29.6	2.90	5.5	4.96	Persistence, HPN

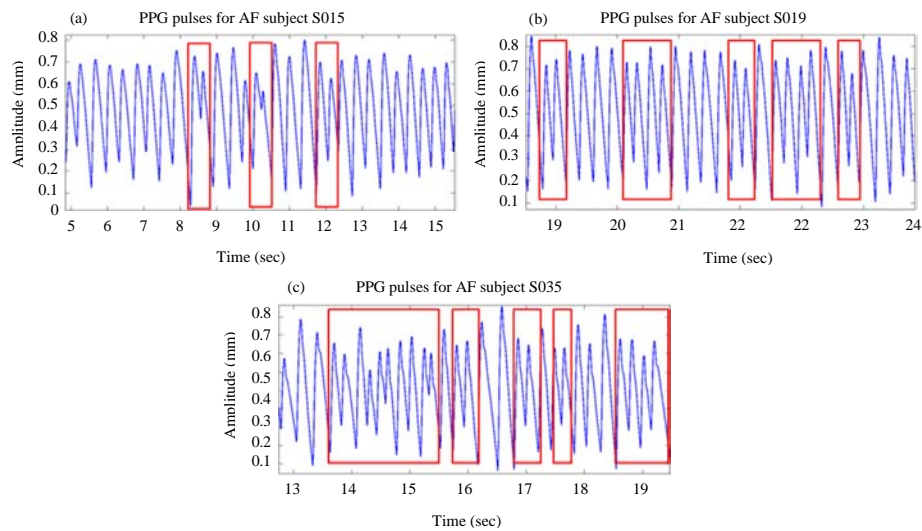


Fig. 4: PPG signal of Paroxysmal AF with: a) 2.15 INR level; b) 2.21 INR level and c) 2.17 INR level

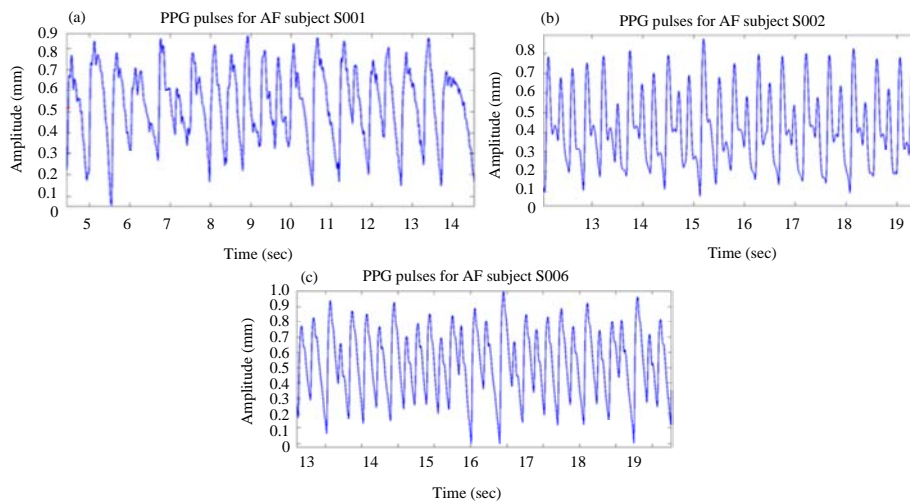


Fig. 5: PPG signal of Persistence AF with: a) 2.13 INR level; b) 2.28 INR level and c) 2.9 INR level

by medication or otherwise their heart will not be able to return back to normal rhythms. The PPG signals of persistence AF show the irregular rhythms happen in almost each of the cardiac cycle. The first and second peaks in PPG signal could not be detected because several cardiac cycles are uncountable when the event of AF are repeated often due to unidentified waveforms on the PPG signals. From these morphological changes on the signal among the paroxysmal and persistence AF subjects, it can be seen the outstanding features on the AF detection based on the comparison against PPG signal from healthy subject. At the moment, we discovered the PPG morphology change shows quite obvious pattern on the PPG waveforms which could be the noninvasive markers for AF conditions.

CONCLUSION

The target INR level between 2.0-3.0 in range is form of an acute AF among paroxysmal AF and persistence AF. This relationship between AF and INR is clinically important due to the warfarin acts as an anticoagulant medicine for AF subjects. AF presentation can be detected by comparing the PPG signal of AF subjects with PPG signal of healthy subject. Paroxysmal AF can be detected from occasional irregularities in the subject's PPG pulses where the total numbers of AF event that happen may be counted. Whereas, for the persistence AF, the PPG signals have uncountable AF events which are reflected in the PPG signals being irregular in most of the pulses. However, this is the first report on the different types of AF signal that can be detected using morphology evaluations on the PPG signals comparing with the healthy PPG signal.

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