Myocardial Infarction and Antiphospholipid Syndrome: a First Study on Finger PPG Waveforms Effects

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Abstract

The aim of this study is to highlight the presence of cardiovascular disease (CVD) using a non-invasive low cost technique: the photoplethysmography (PPG).

This work represents a preliminary study in the time domain of finger PPG signals of patients with acute myocardial infarction (AMI), chronic myocardial infarction (CMI), and Antiphospholipid Syndrome (SAA).

PPG signals were taken using a commercial pulse oximeter. Twelve PPG waveforms were measured for each studied group (AMI, CMI and SAA) and for a group of healthy volunteers. Time domain PPG signal processing was done using a MATLAB implementation of an improved differential algorithm, in order to detect the characteristic parameter 'relative crest time' (T1/TPT), identified from the literature.

The statistical distribution of PPG relative crest time shows that healthy subjects present a relative average crest time below 0.2 and a very tight distribution. On the contrary, patients with AMI, CMI and SAA have a higher mean value of T1/TPT and a wide asymmetrical shape of distribution.

The obtained results suggest that a T1/TPT value above the 0.2 threshold is dangerous for healthy subjects. Moreover, the results extracted from PPG signal of younger patients with SAA seem particularly significant.

1. Introduction

Cardiovascular disease (CVD) covers a wide array of disorders, including diseases of the cardiac muscle and of the vascular system supplying heart, brain, and other vital organs [1]. It represents one of the major causes of death all over the world. In Europe, 40% of deaths are due to CVD. Moreover, CVD mortality is expected to increase in the future because of bad alimentary habits and lifestyles. High cholesterol levels, hypertension and obesity resulting from unhealthy lifestyle, increase the risk of cardiovascular diseases, such as coronary heart disease, heart attack and so on [2, 3]. This work represents a preliminary study in the time domain of finger PPG signals of patients with acute myocardial infarction, chronic myocardial infarction, and Antiphospholipid Syndrome.

Myocardial infarction (MI), commonly known as heart attack (HA), occurs when part of the blood supply to the heart is interrupted as a consequence of the occlusion of a coronary artery [4]. The resulting restriction in blood supply, named ischemia, and oxygen deficit can damage and death of heart muscle tissue. Heart attacks are the leading cause of death for both men and women all over the world. More than one quarter of all myocardial infarctions are silent, without chest pain or other symptoms. Important risk factors are previous cardiovascular disease (such as angina, a previous heart attack or stroke), older age, tobacco smoking, high blood levels of specific lipids (triglycerides and cholesterol), diabetes, high blood pressure, obesity, excessive alcohol consumption, drugs, and chronic high stress levels [5]. Immediate treatment for suspected acute myocardial infarction includes oxygen, aspirin, and sublingual glyceryl trinitrate (i.e. nitroglycerin) [6].

Antiphospholipid Syndrome (SAA), usually present in young patients [7], is a congenital alteration of the plasmatic coagulation that encourages the appearance of blood clots in both venous and arterial vessels.

The standard treatment of chronic MI and SAA diseases is oral anticoagulant therapy (OAT), also called blood thinner. OAT decreases the blood's ability to clot and prevents existing blood clots from getting bigger. Unfortunately, blood thinners can't break up blood clots that have already formed.

Photoplethysmography (PPG) is a non-invasive low cost technique used to analyse many physiological parameters, such as heart compliance, blood viscosity, vessel elasticity and microvascular blood flow and tissue viability [8]. PPG principle has been used in a wide range of commercial biomedical devices for monitoring and measuring heart rate, blood pressure, arterial oxygen saturation, cardiac output and every kind of peripheral

vascular disease detection. It is widely demonstrated that it can provide a lot of information about the cardiovascular system and diseases, although its origins and the physiological information hidden in the different components of the PPG signal remain nowadays not fully comprehended [9].

In this preliminary study, we compared a set of PPG signals of patients with chronic and acute heart attack and with SAA, with a set of PPG measures obtained on a controlled healthy group, taking into account the literature on features analysis of photoplethysmography in time domain for physiological parameters detection.

2. Introduction to pulse oximetry and to PPG signals

A pulse oximeter is a medical device that measures the oxygen saturation of the blood as well as the heart rate. It is usually used to monitor patients during surgical procedures, rehabilitation sessions, sedation, or pain management. The principle of the measurement technique, first used by Hertzman in 1938, is simple. A small light source and a photosensitive detector are applied to the skin. The emitted light is scattered in the tissue and partly absorbed. Part of the scattered light emerges again through the skin, then is detected by the photoelectric cell and recorded as a photoplethysmogram (PPG).

The intensity of the light detected depends on several factors. When the light enters the human body, its path can be modified by anything that it encounters. This includes not only the hemoglobin in arterial blood, but also particles such as skin, bones, muscles, tissues, and venous blood, the blood that carries oxygen toward the heart. To determine what portion of the transmitted light comes from hemoglobin in blood, and what portion comes from skin, bones, and other tissues, can be very complicated. Luckily, arterial blood is pulsatile (Fig. 1).

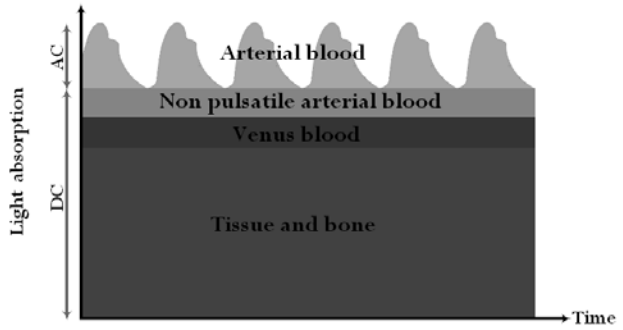

Figure 1. Pulsatile light absorption of red and infrared wavelength in human tissue.

This means that its absorbance of light is an AC signal [10]. All other components found in the human body, including tissue and venous blood, have a constant DC absorbance of light. The isolation of the AC component allows to detect the absorbance of light due only to hemoglobin in arterial blood. The fundamental frequency of AC component is about 1 Hz, because it depends of the heart rate.

From a clinical point of view, only the AC component of the PPG is relevant. It is well demonstrated that its amplitude depends on different factors but its shape is usually the same. Therefore, PPG waveform is mainly conditioned by cardiovascular compliances.

Figure 2 shows two different phases of the PPG waveform: the rising edge of the pulse and the component being the falling edge of the waveform. The first phase is primarily related to systole, and the second phase to diastole and wave reflections from the periphery [8].

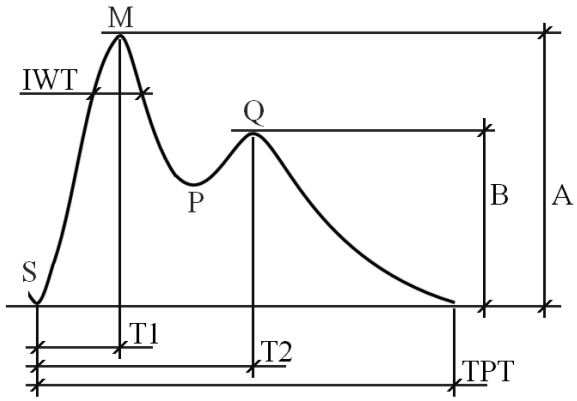

Figure 2. Standard PPG signal and its feature in time domain.

Segment S-M represents the rapid ejection phase while M-P the late phase. At point M, the blood pressure is the highest of the whole period. Point P is called dicrotic notch, while the wavelet Q is called dicrotic wave.

The dicrotic notch is usually seen only in the late phase of subjects with an healthy cardiovascular system. In patient with CVD only 2% of them has PPG with the dicrotic notch, while the 98% has a PPG with a negligible dicrotic notch. For this reason, PPG is usually classified in term of amplitude of the dicrotic notch (Fig. 3).

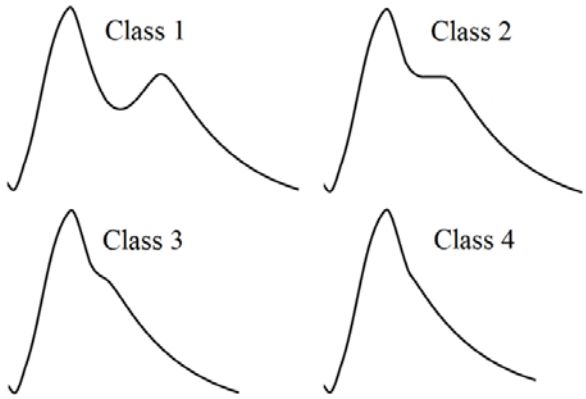

Figure 3. Standard classification of PPG waveforms.

- Class 1: the late phase clearly presents a dicrotic notch;
- Class 2: the late phase doesn't present a notch but there is a horizontal plateau in the falling edge;
- Class 3: the late phase doesn't present a notch but there is a little noise in the falling edge;
- Class 4: the late phase doesn't present a notch and there aren't wavelets in the falling edge;

Class 1 PPG is usually present in healthy subjects while class 4 often characterizes old people and people with dangerous CVD such as MI. Hence, ageing and CVD makes class 4 the most frequent PPG waveform. The transition can be caused by an early reflected pressure wave from the peripheral circulation. With arteriosclerosis, the contribution of the reflected wave is more relevant in the systolic phase instead of the diastolic phase of the PPG.

2.1. PPG signal features in time domain

Figure 2 also shows the features of interest in time domain PPG measurements for physiological parameters detection [11]. In time domain, the following intervals and amplitudes are usually recorded: crest time (T1), dicrotic wave time (T2), total pulse duration (TPT), interwave time (IWT), systolic amplitude (A) and dicrotic wave amplitude (B). Starting from these features, standard parameters calculated in order to detect some physiological indicator are: relative crest time (i.e. T1/TPT), relative dicrotic wave amplitude (i.e. A2/A1) and relative dicrotic wave time T2/TPT.

3. Methods

3.1. Data acquisition

Figure 4 shows the portable pulse oximeter used at hospital for the acquisition of 30 seconds length PPG signals (i.e. LifeMed SAT300) from the fingertip of the right hand of patients.

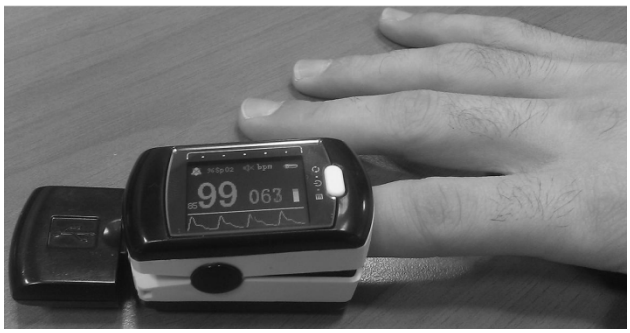

Figure 4. Picture of the commercial pulse oximeter used at hospital in order to acquire the PPG data sets.

It is a commercial battery powered pulse oximeter for arterial oxygen saturation percentage measurement and heart rate calculation, enhanced with a real-time wireless transmitter for PPG data storage and off-line processing. The main limits of this device are the relatively low resolution of its Analog to Digital Converter (i.e. 8-bits) and its low sample frequency (i.e. 60 sps). Taking into account that the first PPG features we need to investigate are time intervals, 60 sps of sample frequency is not sufficient for an efficient time domain data analysis.

All the subjects involved in the trial, were well informed about our research aim and a written informed consent was provided and signed by all of them. We measured 60 PPG waveforms of different healthy volunteers with an average age of 28 years (Table 1).

Table 1. Mean Age of the subjects involved in the trial.

Set	Mean Age [years]
Healthy	28
CMI	68
AMI	62
SAA	47

PPG signals from patients with CMI and SAA were acquired thanks to the collaboration with the Thrombosis Centre of the Policlinic Hospital in Monserrato, Cagliari, Italy. Instead, PPG signal from AMI patients were acquired in the Cardiovascular Department of San Giovanni di Dio Hospital in Cagliari, Italy, within 24/48 hours starting from the occurrence of the symptoms. At the end of the trial we collect 13 PPG signal from each set of patient with CVD.

3.2. Data processing and analysis

It is well known that PPG signals are quite sensitive to noises, such as patient tissue opacity, baseline drift caused by breathing and motion artefacts due to tissue-probe drifts. The automatic detection and deletion of such motion artefacts is a non-trivial computer science exercise. We processed the acquired PPG signals in MATLAB following a well defined signal processing flow:

- Pre-processing stage: we used FIR and moving average filters in order to reduce noise and baseline drift and in order to extract motion artefacts-free PPG segments for safe feature detection algorithm implementation;
- Time-domain processing stage: time-domain PPG signal features was detected using a MATLAB implementation of an improved differential algorithm [12];
- Graphical plotting stage: the results of the data

processing stage was graphically represented by MATLAB box plots.

4. Preliminary results and conclusions

The plot in Figure 5 shows the preliminary result of this research. The statistical distribution of PPG relative crest time (T1/TPT) for the healthy subject, the acute and the chronic heart attack patients, and patients with antiphospholipid syndrome are organized in a box plot. On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, and the whiskers extend the box to the most extreme data points in the record analyzed.

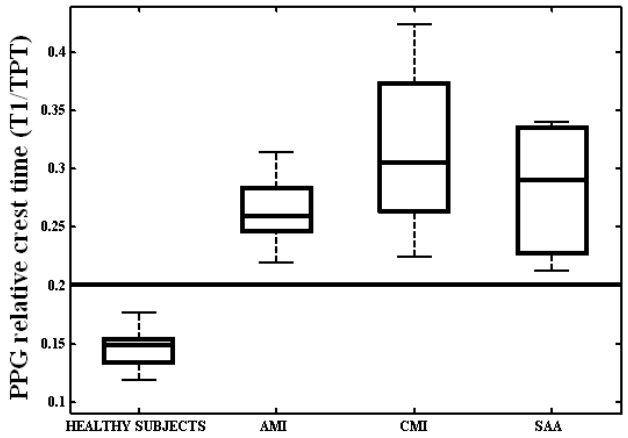

Figure 5. Preliminary results of statistical distribution of PPG relative crest time (T1/TPT).

These preliminary results show that healthy subjects present a relative average crest time below 0.2 and a very tight box height. On the contrary patients with heart attack, both acute and chronic, and SAA patients have a higher mean value of T1/TPT and a wide asymmetrical box of distribution. These results suggest that a T1/TPT value above the 0.2 threshold is a dangerous value for the subject's health.

The next step of this research will provide more samples in the disease sets in order to reinforce the statistical analysis. Moreover, we will build a second healthy data set with an older average age for a clear comparison between the data collection. T2/TPT analysis was not performed because dicrotic notch is usually seen only in PPG signals of healthy subjects.

Acknowledgements

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References

[1] Mathers CD, Lopez AD, Murray CJL. The burden of disease and mortality by condition: data, methods and results for 2001. Global Burden of Disease and Risk Factors. Oxford University Press, New York.

[2] Clark CM, Perry RC. Type 2 diabetes and acute macrovascular disease: epidemiology and etiology. American Heart Journal 1999; 138:330-333.

[3] Schnell O, Schafer O, Kleybrink S, Doering W, Standl E, Otter W. Intensification of therapeutic approaches reduce mortality in diabetic patients with acute myocardial infarction: the Munich registry. Diabetes Care 2004; 27:455-4604.

[4] Heart attack and angina statistics. American Heart Association 2003.

[5] D'Aiuto F, Parkar M, Nibali L, Suvan J, Lessem J, Tonetti MS. Periodontal infections cause changes in traditional and novel cardiovascular risk factors: results from a randomized controlled clinical trial. American Heart Journal 2006; 151: 977–984.

[6] Pearson TA, Mensah GA, Alexander RW, Anderson JL, Cannon RO, Criqui M, Fadl YY, Fortmann SP, Hong Y, Myers GL, Rifai N, Smith SC, Taubert K, Tracy RP, Vinicor F. Markers of inflammation and cardiovascular disease: application to clinical and public health practice: a statement for healthcare professionals from the Centers for Disease Control and Prevention and the American Heart Association. Circulation Journal 2003; 107:499–511.

[7] De Groot PG, Pengo V, Tripodi A. Antiphospolipid syndrome: laboratory detection, mechanisms of action and treatment. Journal of Internal Medicine 2011; 270:110-122.

[8] Allen J. Photoplethysmography and its application in clinical physiological measurement. Physiological Measurements Journal 2007; 28:1–39.

[9] Ando J, Kawarada A, Shibata M, Yamakoshi K, Kamiya A. Pressure-volume relationships of finger arteries in healthy subjects and patients with coronary atherosclerosis measured noninvasively by photoelectric plethysmography. Japanese Circulation Journal 1991; 55:567–575.

[10] Nickerson BG, Sarkisian C, Tremper K. Bias and precision of pulse oximeters and arterial oximeters. Chemistry 1988; 93:515-517.

[11] Korpas D, Hàlek J, Dolezal L. Parameters describing the pulse wave. Physiological Research 2009; 58:473–479.

[12] Wei C, Sheng L, Lihua G, Yuquan C, Min P. Study on conditioning and feature extraction algorithm of photoplethysmography signal for physiological parameters detection. ICSP 2011; 2194–2197.

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