Advanced Potential of the Photolpetismograph PPG-2 in the Non-invasive Vascular Diagnosis

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***Abstract* – Advanced sensor device for shape analysis of the tissue-reflected mean single period photoplethysmography (PPG) signals have been designed and clinically tested. The PPG signal shape reveals individual features of the patient's cardiovascular state. Clinical studies of several patient groups (e.g. diabetes mellitus, atherosclerosis obliterans, Reynaud's syndrome) made it possible to specify components of the PPG signal that are sensitive to the corresponding organic or functional pathologies. Comparison of the right and left arm finger PPG signal shapes, for instance, appears to be an efficient tool for early screening of unilateral atherosclerosis obliterans.**

***Index Terms* – Photoplethysmography, optical bio-sensing, diabetes, atherosclerosis, Reynaud's syndrome.**

I. INTRODUCTION

Photopletismography (PPG) is a noninvasive method which involves the graphic recording of the changes in the volume of a body segment, closely related to the changes in the blood flow during the systolic-diastolic excursion. Photopletismography is a technique developed by Blazek and Wienert in 1981 [1]. This technique, based on different physical principles, has been applied in the clinical evaluation and measurement of arterial and venous blood flow.

The photopletismographic sensor consists of an infrared light diode and a photodiode-strand. Emitted light penetrates the upper layers of the dermis in the case where a part of it is absorbed and another part is reflected and captured by the photodiodes. Reflected light intensity, and therefore the electric signal produced by the photodiode will correspond to the volume of blood in the measured zone. Photopletismography is used as a complementary functional method due to its capacity to highlight the early state of stiffness or muscle spasm of arterioles and capillaries. Comparing the signals from the right and left arms seems to be an effective tool for an early detection of unilateral obstructive atherosclerosis. Photopletismo-graphy examination is easy to implement, however, it often involves multiple nuisances which can lead to diagnostic errors.

Advances in microelectronics and computer technology have opened new possibilities. PPG spectrum analysis provides valuable information on the cardiac function, respiration, vascular and nervous system condition [2, 8]. PPG is easy and safe to use for express-diagnosis and early detection of various cardiovascular diseases.

PPG waveform detected at the periphery may differ significantly from the one detected in the main arteries, and will depend on the strength of the vascular system. If the resistance is abnormal, which is often caused by atherosclerosis, diabetes or other vascular diseases, which reset the narrowed vessels, blood flow velocity in the large arteries to small capillaries decreases dramatically. Hypertension leads to a complete loss of dicrotic peak when it reaches the periphery. Secondary peaks of PPG signals could not be detected on the fingers of patients with hypertension [12].

We should note that PPG signals are not strictly repeated and slight fluctuations of the signal amplitude are possible.

Many doctors prefer visual information (images or diagnostic curve). To provide doctors with such visuals, the Technical University of Moldova, Department of Microelectronics and Semiconductor Devices proposed a photopletismograph (PPG-2). It provides the ability to detect and acquire a signal sequence of 60 individual patients and can specify the exact forms of the signal for further clinical analysis. The available internal memory allows the device to input the data of up to 4000 patients into the database. This data can be later transferred to a PC for further analysis.

The small size of the device and the fact that it is battery powered permits the use of the device for self-monitoring of vascular status at home or during physical exercise, provided that the temperature requirements (22-25C) are satisfied and that the patient is in a calm state of mind.

Below we wanted to demonstrate the capabilities of PPG-2 in the noninvasive diagnosis of cardiovascular diseases and in the analysis of the wave-shaped pulsating blood flow.

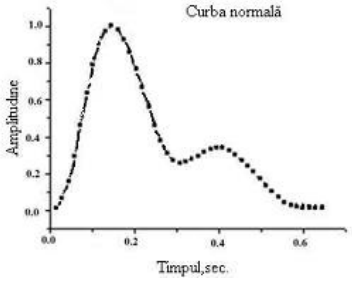


Fig.1. PPG signal form diagnosed at a healthy person

II. MATERIALS AND METHODS

For the purpose of this study we selected a group of practically healthy persons, which gives us the normal parameters of elasticity of the vascular system. Such characteristics have been used in quantitative and qualitative assessment of signal parameters PPG assessed in clinical trials with this device.

Photopletismographic interpretation is based on the evaluation of certain quantitative and qualitative parameters [9,13]. The quantitative parameters include: amplitude curve, speed, time to the wave peak, and total dicrotic notch. The qualitative parameters include: total wave morphology and its components.

Some signals measured initially at a group of persons are presented in Fig. 2. The signals were taken from the same body part (tip of a thumb). Those monitored were practically healthy. The following legend was used: male - A, G and O, age 24-26 years, J - a man of 49 years, M - a woman of 56 years. Figure 2 shows clear differences in PPG signals recorded from five healthy individuals. Dicrotic notch is more pronounced in younger patients [13], which could be interpreted as a good sign of vascular elasticity, compared with older patients.

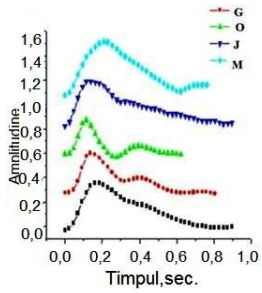


Fig.2. Different types of signals PPG recorded at a group of practically healthy patients.

Our studies in 5 patients with diabetes mellitus have fully confirmed our hypothesis. All PPG signals recorded at the finger tips of these patients were bell shaped, with no secondary peak in the catacrota (Fig. 3).

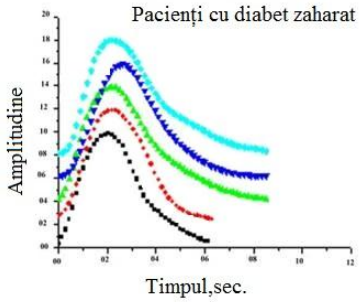
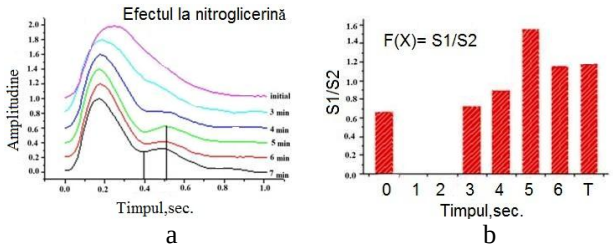


Fig.3. PPG signals in 5 patients with diabetes

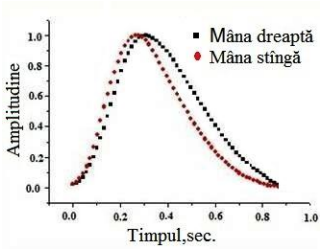
.The clinical trial in patients with atherosclerosis revealed similar types of PPG signals. At a dose of nitroglycerin, reflecting the pharmacological dilation of blood vessels a secondary peak formation was observed. It is a sure indication of an increased blood flow. The changes obtained were shown in Figure 4.



a b

Fig.4. A – demonstrates the changes in patients with asymptomatic mild atherosclerotic changes, which have received a dose of nitroglycerin, B – the time of the nitroglycerin-caused effect development characterized by T2/T1 signal and forming the secondary peak in the catacrota signal. It is a clear indication of an increased blood flow.

Thus we can see a clear time delay and broadening of the signal on the right arm, compared with the left arm, which shows an increased vascular resistance and a slower speed of blood flow in the right arm. Therefore the angle ratio (slope) by signal S left / S right could serve eventually as a diagnostic criterion for assessing blood vessel occlusion (Fig. 5 b).



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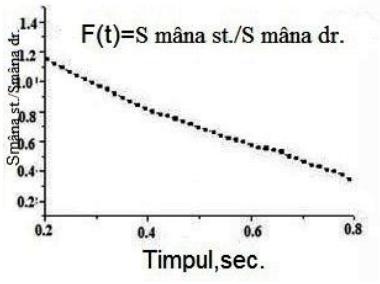
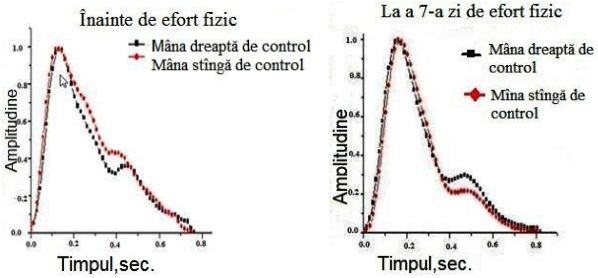


b

Fig.5. a - comparison of PPG signals from the fingers on both hands, in the case of the subclavian artery occlusion, b - the angle ratio (slope) by signal S left / S right

Reynaud's syndrome (RS) is a paroxysmal disorder of the peripheral circulation, located usually in the upper limbs, characterized by intermittent appearance of a bilateral and symmetrical spasm of digital arteries, occurring when the patient experiences cold or emotions, with the normal state in other conditions. It is a rare disease, which is found typically in young women (less than 40 years). The etiology is unknown. PPG can provide additional information about this disease [14, 15].

PPG monitoring was used to monitor vascular changes during a physical exercise of a patient (L., 22 years) with RS. PPG signal was recorded before and after the exercise. Remarkable changes can serve as evidence of the nutrition of the arm "trained" with improved blood. The results are shown in Fig.6.



a b

Fig.6. PPG signals taken from the fingers of both hands before and after the tests in patients with Reynaud's syndrome

III. REVIEW.

The results presented and the analysis of the functional characteristics of the device confirmed the potential of PPG-2 sensor, used in vascular diagnostic methodological procedure and during the exercise test in the pre-clinical phase.

We have also noted other aspects of PPG signals recorded at the finger tips which can serve as criteria for diagnostic

and dynamic screening:

- Growth of the anacrotic phase of the pulse wave characterizes the resistance of the blood flow in vessels;
- General shape of the signals PPG: a bell, with no signs of reduced catacrota and dicrotic notch announces various abnormalities of peripheral blood vessels (caused by diabetes mellitus, atherosclerosis);
- Appearance and increase / decrease of the secondary peak, assessed against a drug (e.g.: nitroglycerin) may be used to monitor the time of expansion / narrowing of blood vessels;
- Changes in the shape of the signal PPG, reached after a physical exercise or a physiological effort (blood flow), reflect the progress of the physiological state of the observed.

IV. CONCLUSIONS

Photopletismography with reflected light proved to be an appropriate tool for testing the prediction of the therapeutic outcome (e.g.: for the patients with high blood pressure, diabetes, obliterating arteriosclerosis and Reynaud's syndrome, etc.)

Having reviewed research that focused on the PPG-2 device performance, we conclude that it offers the possibility of rapid and reliable estimates.

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