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Analysis of the vascular tone and character of the local blood flow to assess the viability of the body using the photoplethysmographic device

***Abstract**. The paper evaluated the vascular tone and character of the local blood flow using photoplethysmographic device to determine the viability of the studied organ and prospects for its preservation.*

***Streszczenie.** W pracy przedstawiono ocenę sygnału naczyniowego i charakter lokalnego przepływu krwi z użyciem urządzeń fotopletyzmograficznych do oceny żywotności badanego narządu i perspektywy jego zachowania (**Analiza napięcia naczyniowego i charakteru lokalnego przepływu krwi z użyciem urządzeń fotopletyzmograficznych do oceny żywotności narządu**).*

Keywords: occlusive disease of lower extremity arteries, collateral circulation, a survey, photoplethysmography.
Słowa kluczowe: zarostowa choroba tętnic kończyn dolnych, krążenie oboczne, badanie, fotopletyzmografia.

Introduction

Today a significant number of leading companies engaged in development and production of diagnostic medical equipment [1]. The most famous ones are: Philips, MEDIC (Medizinische Messtechnik GmbH), Nonin, Cas Medical System, Radiometer, Micromed, Criticare, UTAS (Ukraine) and others. For biomedical devices is not the most important characteristics are painless, noninvasive measurements in the diagnosis. Among the methods that can provide it, occupy a prominent place optical. Optical methods inherent advantages such as noninvasive of diagnostics, optical signal indifference to electromagnetic interference, multi potential. Photoplethysmography technique compared with other diagnostic methods for biological object, such as the photoacoustic method to increase the reliability of registration hemodynamic circulation, and the introduction of fiber elements technology and sources of different wavelengths of radiation allows the probe accurately solve problems photodynamic studies of hemodynamic parameters or other biological object.

In this respect, promising work to create optoelectronic systems for diagnosis, therapy and prediction of the cardiovascular system as an effective universal means of rapid diagnosis of peripheral circulation, allowing for a long time to carry out monitoring of peripheral vascular publish current and averaged diagnosis-information on the physiological state.

Assessment of the viability of a particular patient's body is often presented as a complex practical problem of clinical surgery. Especially when there are no obvious signs of necrosis, which is important when jamming bowel loops, postoperative wounds and critical lower limb ischemia [2–5]. In practice, a survey of diseased organ carried out by evaluation of its appearance, tactile definition of regional temperature and pulsation of the arteries or evaluation of response to external stimuli. During research are studying of microhemodynamics by laser Doppler flowmetry, transcutaneous oximetry and other methods with using stress tests, including a test of reactive hyperemia [2, 3, 5, 6]. These methods image the state of compensatory mechanisms circulation of the lower limbs. However, it is insufficient attention is paid to the investigation of vascular tone and character of the local flow as prognostic keeping organ factors.

The aim is to examine the ability of evaluation of vascular tone and character of the local blood flow to determine the viability of the organ and the prospects for its keeping on the example of the foot.

1. Materials and methods

In the pathogenesis of the absolute majority of clinical diseases present specific first phase - a violation of blood circulation. Therefore, treatment in a disease should be based primarily on the restoration of blood circulation in the body. Therefore, finding, development and improvement of technologies normalization of blood circulation in the human body and peripheral blood evaluation methods have always been, are and will be important task for developers of new medical equipment.

Among the known factors that are used to improve blood circulation, the most effective, completely safe and natural for humans is electromagnetic radiation in the optical range of the spectrum (light) and constant magnetic field.

Study of effect of these factors on blood circulation and development of technologies and related devices, and monitoring of human health is impossible without diagnosis or evaluation of peripheral blood circulation in the body. The most advanced methods nowadays considered optoelectronic conversion methods of registration and biometric information.

By non-invasive optical methods for diagnosing peripheral circulation refers PPG method to increase the reliability of the control of blood circulation in the diagnosis of early stages of the most common human diseases.

Significant advances in the pharmacotherapy of recent decades could not solve the problem of effective treatment of certain diseases. Moreover, there was a group of diseases and pathological conditions associated with the use of modern medicines. The number of diseases resistant to treatment. In some cases, treatment is aimed at combating the effects of disease, not its cause. This path can not be considered promising.

Therefore, it remains questionable finding and developing non-drug treatment and prevention of the most common human diseases, aimed at addressing the root causes of these pathologies. As such the primary cause in most cases is a violation of blood circulation in the human body, the question of the development of technologies and methods of restoring blood circulation its assessment remain in the zone of maximum attention of scientists, doctors and engineers.

Improving the informativeness and reliable assessment of peripheral blood circulation in the body and increase the efficiency of prevention and treatment of common human diseases by developing optoelectronic noninvasive means for normalizing blood circulation using low-intensive electromagnetic radiation in non-monochromatic optical range.

Stand investigations were carried out on the layout, which included tubes with hard and soft walls. Sodium chloride solution 0.9% and diluted canned erythrocytic mass of sodium chloride 0.9% at a ratio of 1:1 were passed through the tubes in continuous and discontinuous ("pulsing") mode at the same pressure and rate (60 ml/min). A photoplethysmographic sensor has been set on the surface of the tubes with different properties.

2. Subsequent recognition

There were examined 108 patients aged 18 to 82 years in total. They were divided into 4 groups: I – 31 persons without evidence of ischemia of the lower limbs, II – 27 patients with 2nd stage of ischemia, III – 29 patients with 3rd stage ischemia, IV – 21 patients with 4th stage ischemia. In the third group selected two subgroups: IIIA stage – no swelling of the foot (11 patients) and IIIB stage – swollen foot (18 patients). Was conducted physical examination, ultrasound scan, arteriography and determining of the level of regional systolic blood pressure.

To assessment of local blood flow we conducted laser photoplethysmography (LPPH) using developed photoplethysmographic device (Fig. 1). The nature of blood flow was determined by the shape and amplitude of the received signal (Fig. 2).

A high-amplitude shape of regular discontinuous signal corresponded to pulsatile blood flow with large volume and a low-amplitude shape of irregular chaotic signal corresponded to nonpulsatile blood flow.

The main investigation areas were the first fingers and toes, prebrachial joint and the middle third part of the tibia.

Fig.1. Developed photoplethysmographic device

In doubtful for diagnosis and prognosis cases was evaluated the change of signal in the reactive hyperemia conditions.

3. Discussion of results

In bench researches, when it was continuous flow of liquid in tubes with solid and soft walls, was registered low-amplitude, irregular, chaotic, approximate to the background, signal. It form was like a signal obtained in patients with IV stage of ischemia. When it was the "pulsatile" liquid flow from the surface of tubes with soft walls there was obtained regular intermittent signal. It shape was as shape of the signal with the absence of pathology of major arteries. And on the surface of the tubes with solid walls was obtained the same regular signal, but it had smaller amplitude.

The patients without signs of ischemia and pathology of the main arteries of the lower limbs at all levels were registered with a high-amplitude regular intermittent (30 people) or low-amplitude (1 person) signal. The high-amplitude, regular signal was registered in the projection of the arteries, when were determined their pulsation using palpation. The amplitude of the signal at the first toe accounted for 0.81 ± 0.08 of the amplitude of the signal thumb. 3 patients had swelling and some structural features on the ankle area thus palpable pulsation in the artery and posterior tibial artery rear foot not determined. After LPPH blood flow of foot was defined as high-amplitude, regular signal, and after ultrasound scan was defined the main flow.

In patients with II stage of ischemia has been dominated (92.6%) peer occlusion. Ultrasound scanning in the main arteries below the occlusion showed collateral compensated or main modified blood flow. After LPPH, in 19 patients was recorded the intermittent, high-amplitude signal, in 8 patients – low-amplitude signal. The amplitude of the signal at the first toe was 0,26 ± 0,06 and the amplitude of the signal thumb ($p < 0.05$). During the reactive hyperemia test noted the rapid (within 21,8 ± 1,9 p) reaction with increasing amplitude of the signal at 34,7 ± 3,9%. In 4 patients pulsation in popliteal, posterior tibial artery and the artery rear foot not determined palpable. After LPPH blood flow of studied arteries was defined as low-amplitude, regular signal, and after ultrasound scan was defined compensated collateral flow.

Among patients with III stage of ischemia predominated multi-occlusion (79.3%). Ultrasound scanning of the main arteries below the level of the occlusion showed decompensated collateral blood flow. After LPPH 5 patients with IIIA stage of ischemia was detected low-amplitude regular intermittent signal, 6 – low-amplitude irregular, chaotic signal. The amplitude of the signal at the first toe was 0.12 ± 0.04 of the amplitude of the signal thumb ($p < 0.05$). The reactive hyperemia test showed the slow (over 68.7 ± 1.6 p) reaction with increasing amplitude of the signal at 16.7 ± 4.3%. Among patients with IIIB stage of ischemia 4 of them was recorded low-amplitude regular intermittent signal, 14 – low-amplitude irregular, chaotic signal. At the shin was recorded low-amplitude regular intermittent signal with a ratio shin / forearm 0.23 ± 0.07. After the reactive hyperemia test noted slaw (85.4 ± 2,1 p) reaction with increasing amplitude of the signal at 13.4 ± 2.3%.

3 patients during the test had low-amplitude, irregular, chaotic signal that converted into a regular and it amplitude was growing. In the projection of the arteries, which pulsations are not determined by palpation during LPPH recorded low-amplitude, irregular, chaotic signal, during ultrasound scanning – decompensated collateral blood flow. Among patients with IV stage of ischemia were predominated (90.5%) multi-occlusions. During ultrasound scanning in the main arteries below the occlusion level, blood flow was not detected. At the foot LPPH it was received low-amplitude, irregular, chaotic signal. During the reactive hyperemia test increasing of amplitude of signal was not detected. Attempts to amputation at the levels where received a similar signal (7 persons) were unsuccessful. Amputations of lower leg/foot were successful in cases when were registered regular intermittent signals. At the shin was recorded low-amplitude regular intermittent signal with the shin / forearm ratio 0.15 ± 0.04. In the projection of the arteries, which pulsations are not determined by palpation, during LPPH was recorded low-amplitude, irregular, chaotic signal; during ultrasound scanning – decompensated collateral blood flow or it absence.

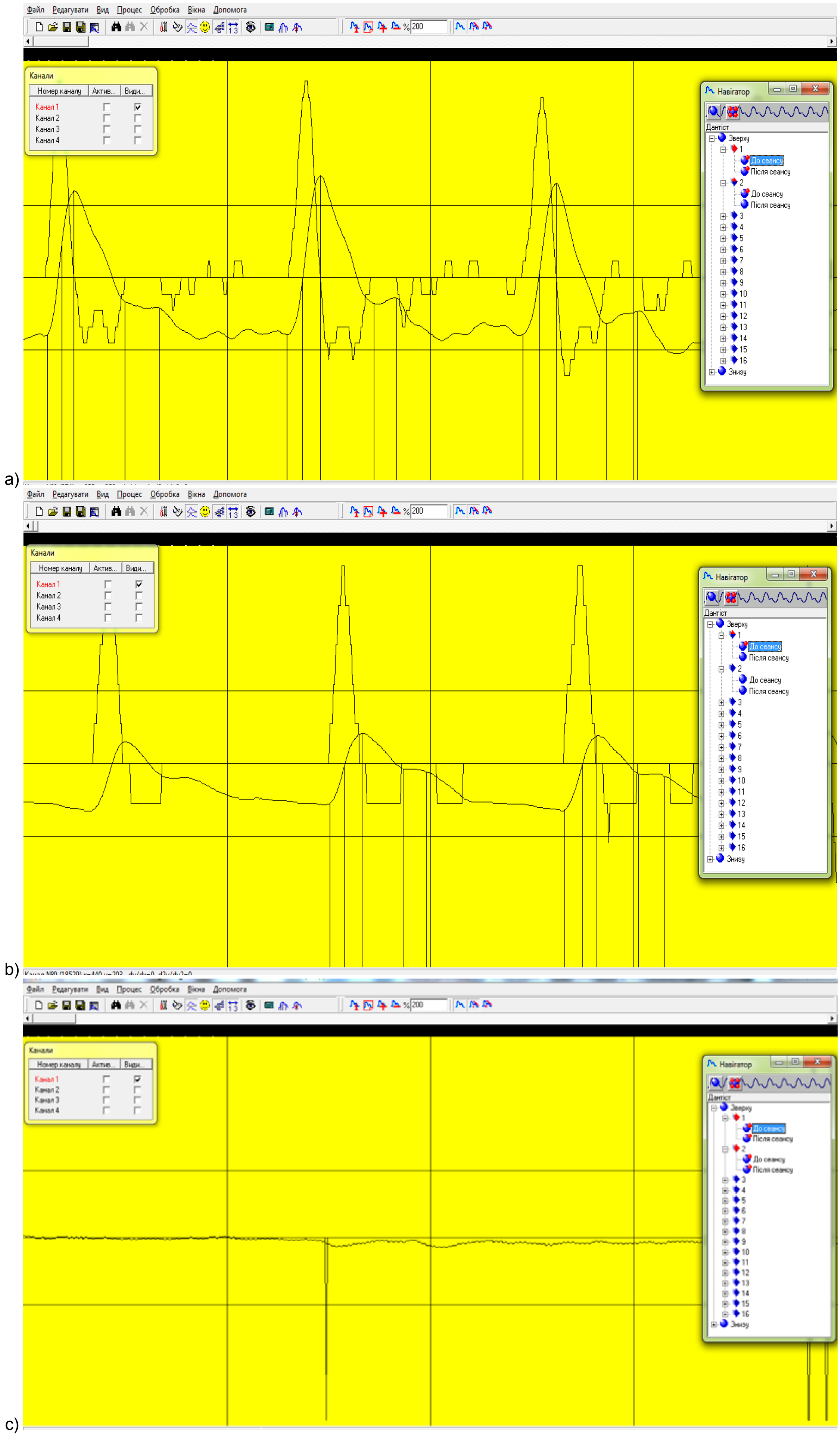

Fig.2. Determining the flow of blood: a) high-amplitude pulsatile; b) low-amplitude pulsatile; c) nonpulsatile

During 12 months in the cases of registration of high-amplitude regular intermittent signal, disease was stable and critical ischemia was not developed. Among patients, who was detected low-amplitude regular intermittent signal (17 persons) it was occurred need for amputation in 2 patients who had practically no reaction on the reactive hyperemia test. After detecting low-amplitude irregular chaotic signal (41 patients) the need for amputation occurred in 36 cases.

It is known that laser Doppler flowmetry based on measuring of the Doppler component in the spectrum of the reflected laser signal scattered by erythrocytes moving [6]. Bench tests show that LPPH responds to the tone of the vessel's walls, changes of it elasticity and nature of the fluid flow. Tonus of the vascular wall acts as a mediator. Main registered phenomenon is the nature of the blood flow. Besides it, as we studied earlier, morphological changings of collaterals is less significant, than in the main arteries. Consequently, tone changes are just one of the factors in shaping signal during LPPH. Form of the received signal corresponds to the nature of blood flow. Regular intermittent signal corresponds to a pulsatile flow and low-amplitude irregular chaotic signal corresponds to no nonpulsatile flow.

II stage of ischemia occurs spasm of arterioles and precapillary sphincters and increased peripheral resistance. III–IV stages of ischemia, on the basis of deep tissue hypoxia, significantly decreases tone of the vessels, including arterioles, venuljarnom shunts and there are deep microcirculatory disorders, significantly decreases or disappears systolic velocity of blood flow, progressively deteriorating collateral flow. At the same time flow pressure reduced at a proximal level. The pulsating nature of blood flow "extinguished" and it is approach to intermittent nonpulsatile signal [4, 7–9]. The blood flow through the microcirculatory channel loses discontinuity that characterized it in the absence of vascular pathology [10]. Nonpulsatile flow is a factor of endothelial dysfunction and vasoconstriction [11]. The vasoconstriction in such circumstances is virtually impossible. This explains the severe clinical manifestations and futility of preserving an appropriate level of extremity.

During the reactive hyperemia test significantly increases the rate of blood flow, which the endothelial cells very sensitive to, that significantly increase the production of nitric oxide [12–15]. In patients with preserved reserve of collateral circulation recorded a strong reaction. With the progression of arterial disease and decompensation of regional circulation on the basis of endothelial dysfunction, reaction progressively weakens and disappears. The ability to increase the amplitude of the signal and appearance of the pulsatile flow regarded as a feature of preservation of functional reserve and relatively good prognostic sign.

The ability to estimate the pulsatile is the most valuable property of LPPH. Even significantly reduced pulsatile is evidence of sufficient supply of tissues at the resting state and provides perspectives for healing surgical wounds, including amputations.

Conclusion

As a result of studies identified that low-amplitude irregular, chaotic signal, corresponding to the flow nonpulsatile signal, is the predictor of critical limb ischemia and it could be lost for 12 months. A limb segment below the level of losing pulsatile character of blood flow is wasted for it saving. In practical terms, the value of the work consists in receiving of new technical solutions implementing photonic processing systems for the analysis of biomedical information and microcirculatory hemodynamic parameters, providing structure of the automated system with high levels of diagnostics and its functioning algorithm.

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REFERENCES

[1] Maciejewski M., Zastosowanie i ograniczenia technologii informacyjnych w diagnostyce medycznej, *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska*, 2015, 1, 66–72
[2] Gonchar M.G., Clinic-diagnosis of morfohistochimical viability of the lower extremities in diabetic angiopathy a stage of critical ischemia*, Lviv Medical Journal*, T. 14 (2008), Nr 2, 42–44
[3] Mishalov V.G. et al., Diagnosis and treatment of chronic critical lower limb ischemia, combined with multifocal atherosclerosis: guidelines, Kiev (2007)
[4] Kashibadze K.N., Analysis of the results of treatment of patients diagnosed with bowel infarction, *Erebuni Medical Bulletin*, 29 (2007), No 1, 2–10
[5] Polyanskiy Yu.I., Assessment method of bowel viability, *Clinical Anatomy and Operative Surgery*, T. 10 (2011), Nr 3, 72–73
[6] Crupatkin A.I., Laser Doppler Flowmetry of blood flow, *Medicine*, Moscow (2005)
[7] Guch A.A., Factors of development of of arterial long-lasting insufficiency in defeat abdominal of aorta and the part of periferal arteries, *Surgery of Ukraine,* 2 (2002) 74–75
[8] Guch A.A. et al., Changes in regional hemodynamics and microcirculation in the tissues of the lower extremities in patients with atherosclerosis obliterans in I-II st., *Clinical surgery*, 6 (2003), 25–27
[9] Chernyak V.A., The defeat of the peripheral veins of the lower extremities with chronic critical ischemia, *Heart and blood vessels*, 1 (2007), 87–95
[10] Gayon A.K., Medical physiology, Logocfera, Moscov (2008)
[11] Tsygan N.V. et al., Neuroprotection in reconstructive operations on the aortic arch, *Herald of the Russian Academy of Military Medicine*, 38 (2012), Nr 2, 119–127
[12] Hutton P., The benefits and pitfalls of pulseoximetry, *Brithish Medical Journal*, 307 (1993), 457–458
[13] Celermajer D.S. et al., Non-invasive detection of endothelial dysfunction in children and adults at risk of atherosclerosis, *Lancet*, 340 (1992), 1111–1115
[14] Stoneham M.D., Knowledge about pulseoximetry among medical and nursing staff, *Lancet*, 334 (1994), 1339–1342
[15] Pavlov S.V., Kozhemyako V.P., Petruk V.G., Kolisnik P.F., Photoplethysmographic technologies of the cardiovascular system control, *Universum*, Vinnytsia (2007)