Optical sensor systems for noninvasive biomedical research

© A.Yu. Zaitceva, M.S. Mazing

Institute of Analytical Instrument Making, Russian Academy of Sciences, St. Petersburg, Russia
E-mail: anna@da-24.ru

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The paper considers the basic principles of the method for assessing a human functional state through studying the microvasculature response to load. A noninvasive assessment of microvasculature impairments during a functional test with local ischemia was performed using the developed hardware/software complex based on near-infrared spectroscopy.

Keywords: optical sensors, near-infrared range, microcirculation, functional state.

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The human functional state and functional reserve are important indicators characterizing the body resistance to various cardiovascular diseases. Deviation of the main parameters from the standard values evidences for deterioration of the functional state of the body as a whole; this is why early diagnostics of this system is so important. In clinical practice, skin is an object conventionally accessible for functional diagnostics of the microvasculature (MVC) state [1]. It is known that local blood flow detected in the skin quite accurately reflects the general regularities of responses to various physiological stimuli (stress, muscle loads, temperature gradients) of MV as a whole; therefore, studying the local blood flow is an accessible way of diagnosing adaptive vascular reactions of the entire body [2].

Near-infrared spectroscopy (NIRS) was for the first time described back in 1977 as a method for assessing the cerebral vessels physiology [3]. This technique is essentially based on the ability of near-IR radiation (650–950 nm) to penetrate deep into tissue and be partially absorbed by physiological chromophores (hemoglobin, myoglobin, cytochrome, etc.), which allows determining the tissue hemoglobin saturation with oxygen [4].

The goal of this study was a noninvasive assessment of MVC impairments in performing the functional test with local ischemia with the aid of the developed hardware/software complex based on the NIRS spectroscopy.

As a sensor, a noninvasive tissue oximeter developed at the Institute of Analytical Instrument Making of RAS (St. Petersburg) was used. The device played the role of a source and detector of radiation in the visible and near-IR ranges operating at 18 wavelengths (410, 435, 460, 485, 510, 535, 560, 585, 610, 645, 680, 705, 730, 760, 810, 860, 900, 940 nm) and equipped with a microprocessor for data processing and visualization (Fig. 1).

Fig. 2 presents the emission spectrum of the NIRS-based optical sensor system.

Using the device spectrophotometric channel, the volumetric blood filling of the tissue microvasculature in the measurement area was estimated. Estimation was performed by the method of absorption spectroscopy of the light-scattering and radiation-absorbing media. Since microcirculatory impairments do not always manifest themselves under the resting conditions, functional stress tests were required to reveal hidden microcirculatory dysfunction.

The experimental study involved 20 apparently healthy subjects 20 years old, both male and female. In the course of experiment, the subjects remained in a sitting position. After 1 min at rest, an occlusion test was performed without interrupting the record. In 3 min, the cuff pressure was released, and measurements were continued for another 4 min (post-occlusion period). Thus, the total time of the test was 8 min for each subject. The main purpose of the occlusion test as a functional load was promotion of vascular reactions. The venous and/or arterial blood flow in the limb was blocked for a short time by using the tonometer cuff. The relationships between the perfusion and parameters characterizing metabolic processes in biological tissue were analyzed [5,6]. Reserve capabilities of the systems were assessed by the increase in blood microcirculation parameters taking place during post-occlusion hyperemia [7].

Values of the parameters of visible and near-IR radiation backscattered in biological tissues were obtained for each subject before, during and after the functional load. The tissue response indicators for each subject allowed reflecting information on the oxygen supply and dynamics of subjects' MVC parameters variations over the entire period of experimental study. Further processing of the experimental results was performed by using a program package for data analysis. Diagrams representing a set of numerical values of the sensor responses were constructed in dependence on the wavelength (in arbitrary units). Fig. 3 demonstrates the recorded variations in microcirculation parameters versus wavelength and time for a typical subject.

In analyzing the experimental results, individual typological features of the tissue blood flow state were revealed; they

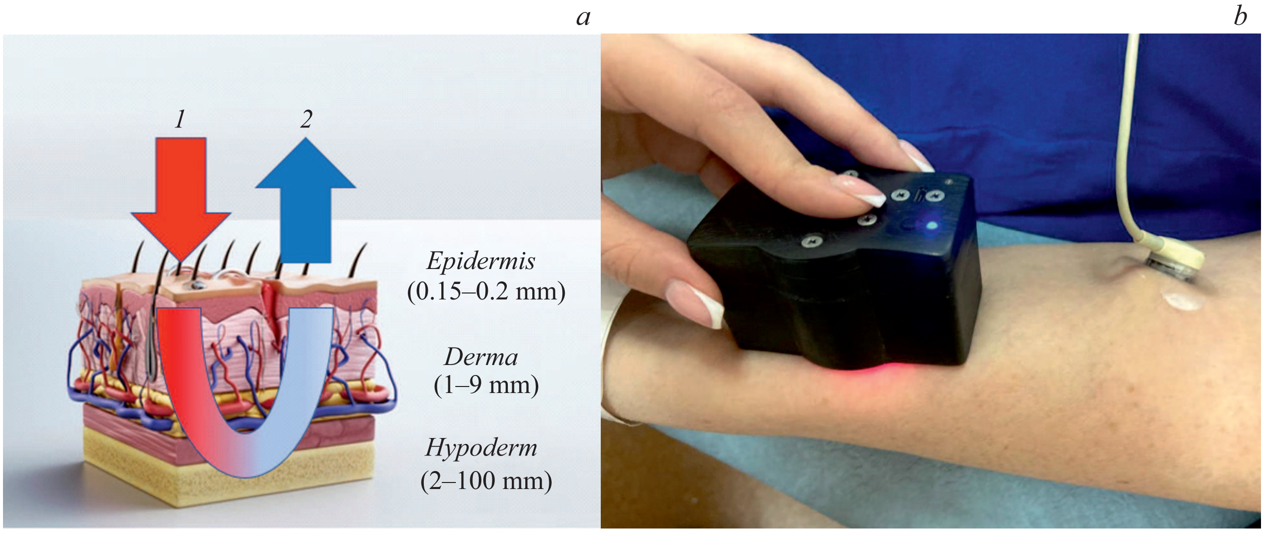

Figure 1. *a* — schematic illustration of the operating principle of the NIRS-based optical sensor system. *1* — radiation source, *2* — detector. *b* — noninvasive tissue oximeter used in the study (Institute of Analytical Instrument Making, RAS, St. Petersburg).

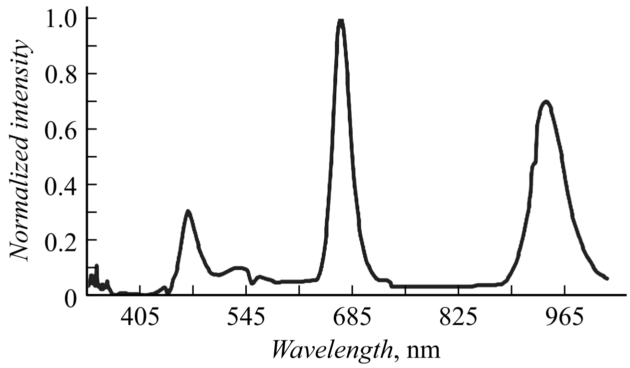

Figure 2. Emission spectrum of the NIRS-based optical sensor system.

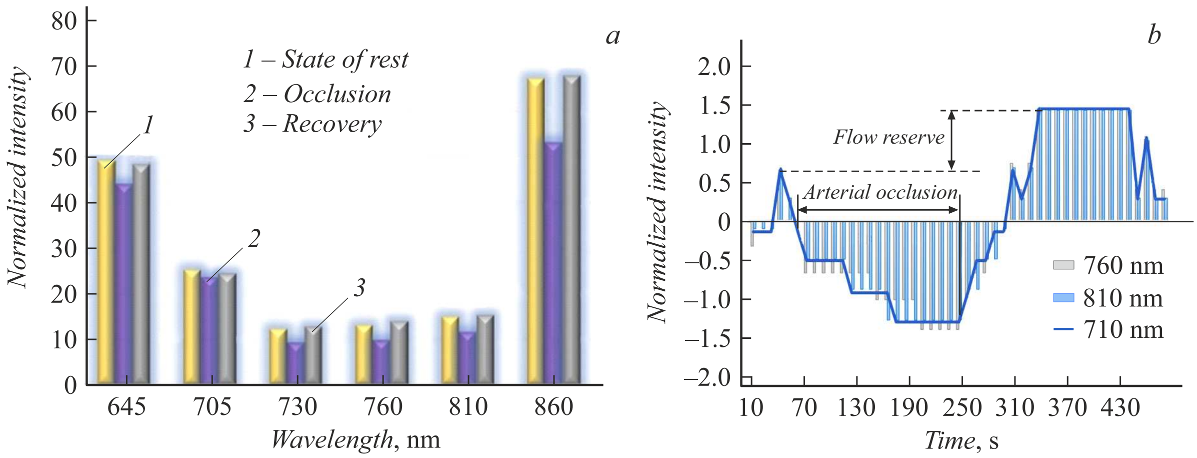

Figure 3. Variations in microcirculation parameters during a stress functional test (occlusion) of upper extremities. The tissue blood flow for different near-IR wavelengths (*a*) and its time dependence (*b*).

reflected the vegetative status of the subjects. It has been shown that backscattered radiation intensities at the selected wavelengths decrease significantly during occlusion and get restored to the values at rest and higher (Fig. 3, *a*). Thereat, the severity of artificial limb ischemia which can manifest itself as a gradual decrease in the readings of sensors of the developed optical system during occlusion appeared to be similar in all the subjects. However, restoration dynamics of blood flows in the limb arteries was different in different subjects. This shows that the microvasculature response to the occlusion test is not identical among the subjects. Another important indicator is the blood flow reserve which can be determined by the difference in sensor readings before and after occlusion. The blood flow reserve is the variation in volumetric blood filling from minimum values during occlusion to maximum ones during post-occlusion hyperemia. This parameter can be determined by the difference between readings of the system optical sensors in the subject in the initial state and after the functional load. Fig. 3, *b* illustrates the graphical method for determining the blood flow reserve. An increased value of this parameter may indicate a circulatory impairment, for instance, the presence of a pathological narrowing of the vessel lumen due to inappropriate contraction of vessel walls. A decreased blood flow reserve may be observed in the case of vessel congestion. In addition, the adaptive reserve of the capillary blood flow characterizes the microvasculature type; therefore, this parameter can be used not only to assess the state of the blood microcirculation system, but also as a criterion allowing one to reliably identify individual typological features of the human blood microcirculation and microhemodynamics with subsequent assessment of manifestation of the pathological processes development.

The analysis of research results allows noticing the efficiency of the developed method for assessing the microcirculation state in order to assess the human compensatory-recovery reactions, functional state and performance.

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Compliance with Ethical Standards

All the human trials comply with Ethical Standards of the institutional and/or national research ethics committee, as well as with Declaration of Helsinki (1964) and its subsequent amendments or matched ethical norms. An informed voluntary content was obtained from each trial participant.

Conflict of interests

The authors declare that they have no conflict of interests.

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