Biophotonics methods for study the functional state of microcirculatory-tissue systems during long-term isolation in the ground model of a space station and in space flight conditions

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From the very beginning of human exploration of Space, considerable importance has been given to the study of the weightlessness effect on the cardiovascular system. Currently, there has been a steady increase in interest in the problems of non-invasive research not only of the microcirculatory bed as the final segment of the cardiovascular system, but also of the microcirculatory-tissue systems (MTS) of the human body. MTS are the smallest functional unit of the vascular system, where microvessels are in close interaction with the surrounding tissue and regulatory elements. The study of MTS functional state, both under the simulation of spaceflight (SF) conditions, like in an isolation experiment, and in a real SF, opens up new opportunities for a more detailed analysis of microvasculature and oxidative metabolism of biological tissue adaptation [1]. The purpose of this work is to demonstrate the capabilities of biophotonics methods for analyzing the functional state of MTS of the human body during long-term isolation in the ground model of a space station and in space flight conditions.

To study the MTS in the Space conditions wearable multimodal devices with laser Doppler flowmetry (LDF) and fluorescence spectroscopy (FS) channels “LAZMA PF” (SPE LAZMA Ltd., Russia; in EU/UK this device is made by Aston Medical Technology Ltd., UK as “FED-1b”) were used [2]. The following parameters were recorded and analysed: index of microcirculation (I_m), amplitudes of endothelial (A_e), neurogenic (A_n), myogenic (A_m), respiratory (A_r) and cardiac (A_c) oscillations, and the skin autofluorescence value (A_{NADH}) when probing with 365 nm light, normalised to the backscattered radiation.

MTS research is currently being conducted on volunteers under isolation conditions. The 360-day isolation experiment (SIRIUS-23 project) simulates the conditions of a long-term manned Space mission in order to study the biomedical and psychological problems in humans associated with isolation and restriction of space. The research protocol includes simultaneous registration of MTS parameters on the back of the wrist and the pads of the first toe. MTS parameters were recorded in a supine position for 10 min (basal conditions), then hyperventilation breathing (6 times per min) was performed for 5 min. The next part of the protocol was executed without the device on the toe since volunteer performed an orthostatic test (standing in upright position). Then volunteer took a horizontal position, and 3 min occlusion test was performed. Measurements of MTS during the simulation of individual SF factors were also performed and showed an active response of MTS parameters to functional tests. It was shown, that, when exposed to the overload during rotation of cosmonauts on a centrifuge, there is a decrease of I_m in the legs and forehead skin, showing the blood circulation is centralized. Changes in MTS parameters of participants of the SIRIUS-23 experiment reflect changes in their functional state due to physical inactivity and changes in psycho-emotional background.

During LAZMA experiment (from December 2021 to the present time) on the International Space Station (ISS) two devices were symmetrically placed on the pads of the middle fingers and big toes, on the back of the wrists and attached to the temples [3]. Measurements of each area lasted 8 min, during which the cosmonauts were in a state of complete physical and psychological rest. Subsequently, the experimental protocol was adapted and shortened to 30 min and included measurements in 3 areas of interest (forehead, fingers and toes). The obtained data demonstrates that the toes are the most stressed areas during the microgravity, which also reflects a decrease in the I_m and oxidative metabolism index in the first days of SF. A preliminary analysis of data on 1 cosmonaut and 1 space tourist showed that the most significant changes in MTS parameters occur in the temporal region of the head and in the region of the lower extremities on the 2nd and 3rd days of SF and are characterized by a significant decrease in I_m and an increase in vascular tone with gradual restoration of pre-flight values by the 6th day of SF. It can also be concluded that the human body strives to maintain the hemodynamics of the brain at a constant level and this area adapts most quickly to new conditions. Thus, for the first time, a technique has been developed for measuring MTS in the limbs of cosmonauts during the period of acute adaptation to microgravity conditions and readaptation after the completion of a SF. Obtaining the most important physiological information in real time under conditions of zero gravity will provide completely new data on the physiology of the MTS in humans under conditions of orbital flight.

Thus, the use of biophotonics methods in portable analyzers during space research (on Earth and in Space) makes it possible to assess the functional state of the MTS of the human body and individualize both the processes of preparing cosmonauts for space flight and their adaptation directly to weightlessness conditions.

[1] A. Dunaev, J of Biomedical Photonics & Eng 9(2), 020201, 2023.
[2] E. Zharkikh et al, J. Biophotonics 16 (9), e202300139, 2023.
[3] A. Dunaev et al, Proc. of Int. Conf. Laser Optics (ICLO), 2022.