Microcirculatory-Tissue Systems of the Human Body as an Object of Study in Space Research

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Current research is investigating the influence of space factors on blood microcirculation and oxidative metabolism, both during spaceflight and in ground-based simulations.

Keywords — space flight, microgravity, blood microcirculation, oxidative metabolism, laser Doppler flowmetry, fluorescence spectroscopy, wearable photonics, microcirculatory-tissue systems.

I. Introduction

The microcirculatory-tissue systems (MTS) of the human body consist anatomically of a network of capillaries, biological tissues, and lymphatic vessels. These systems are pivotal in initiating the body's adaptive responses. The factors of spaceflight (SF), especially weightlessness, cause a global restructuring of the work of various body systems, primarily the cardiovascular system [1]. The study of MTS functional state with non-invasive methods both under the conditions of ground-based simulations of isolated spaceflight factors and in a real spaceflight opens up new opportunities for a more detailed analysis of microvasculature and oxidative metabolism of biological tissue adaptation [2]. This work aims to demonstrate the capabilities of analyzing the functional state of human body MTS under spaceflight and ground-based simulations of isolated spaceflight factors through the use of wearable multimodal photonics devices.

II. Materials and Methods

For our studies, we employed wearable multimodal photonics devices equipped with laser Doppler flowmetry (LDF) and fluorescence spectroscopy (FS) channels, namely the "LAZMA PF" (produced by SPE LAZMA Ltd., Russia and as "FED-1b" by Aston Medical Technology Ltd., UK in the EU/UK). These devices were used during the LAZMA Space experiment, which started in December 2021 on the International Space Station (ISS). Devices were placed on various body points such as the middle fingers, big toes, wrists, and temples. Initial measurements at each site lasted 8 minutes while the astronauts rested completely. Subsequently, the experimental protocol was adapted and shortened to 30 min and included measurements in 3 areas of interest (forehead, fingers and toes) in second set of measurement in March 2024.

Additionally, MTS studies with volunteers under simulated spaceflight conditions including isolation (SIRIUS-23 project), altered air composition, orthostatic stress, and g-forces up to 8g, have been conducted at the Gagarin Research & Test Cosmonaut Training Centre to prepare astronauts for spaceflight. The SIRIUS-23 project, which lasts 360 days, is designed to simulate the conditions of a long-duration human spaceflight mission to study the biomedical and psychological problems associated with human isolation and confinement. The research protocol includes simultaneous registration of MTS parameters before, during and after impact of each factor (hyperventilation breathing, orthostatic test and arterial occlusion).

III. Results and Discussion

The acute adaptation of the body to microgravity is characterized by a deterioration in blood supply: a decrease in the index of blood microcirculation (I_m) with an increase in vascular tone. The vasodilation occurs on the 2^{nd}-3^{rd} days of SF, along with hypercompensatory redistribution of fluid and blood to the lower parts of the body. The use of a prophylactic device "Braslet" delays the onset of adaptation during the time it is worn. As a result, by the 6^{th} day of SF without "Braslet", MTS parameters in cosmonauts' legs return to pre-flight levels. However, these changes are less noticeable in temples and forehead skin, suggesting that MTS regulation differs in these areas.

Measurements of MTS during the simulation of individual spaceflight factors showed an active response of MTS parameters to functional tests. Thus, when exposed to the overload during rotation of astronauts 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.

Obtaining information about the impact of simulated SF factors on the MTS during cosmonauts training and measurements with the use of the developed methodology during a real SF will allow us to develop predictive criteria for the quality of the human body adaptation to zero gravity conditions, and monitor the functional state of the body and the effectiveness of preventive measures taken at the MTS in real-time using wearable multimodal photonics devices.

Acknowledgment

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References

[1] P. Jirak, et al., "How spaceflight challenges human cardiovascular health," Eur. J. Prev. Cardiol., vol. 29(10), pp. 1399-1411, 2022.

[2] A. Dunaev, "Wearable Devices for Multimodal Optical Diagnostics of Microcirculatory-Tissue Systems: Application Experience in the Clinic and Space," Journal of Biomedical Photonics & Engineering, vol. 9(2), pp. 020201, 2023.