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Space Medicine: Scientific Foundations, Achievements, and Challenges

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Abstract—This article, based on a report presented at the Scientific Session of the Russian Academy of Sciences, highlights the history of the formation of space medicine, its theoretical foundations, and the role of scientists of the Academy of Sciences in the preparation and implementation of the first manned flight into space. The achievements of domestic specialists in space physiology, biology, and medicine promoting the development of manned cosmonautics are considered. Examples are given of the implementation of the results of space research, as well as instruments and devices for medical support of space crews, into practical health care. The problems of medical support of future interplanetary flights and the ways of their solution are analyzed.

Keywords: human spaceflight, space physiology, medical support for space crews, interplanetary missions.

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Sixty years ago, an event took place that was of tremendous universal significance—the first human flight into space. The flight of our compatriot Yuri Alekseevich Gagarin became not only our national pride but also the beginning of the realization of the aspirations of many generations of people living on planet Earth. Therefore, it is not by chance that the United Nations at its General Assembly designated April 12 as the International Day of Human Space Flight.

American astronaut Neil Armstrong said about Gagarin: “He called us all into space.” In the first place, this phrase means the burst of enthusiasm of scientists all over the world regarding the provision of spaceflights and the creation of broad international cooperation in this area—cooperation that has been successfully carried out at various levels ever since. That enthusiasm involved representatives of medicine as well. April 12, 1961, was the birthday of not only

manned cosmonautics but also space medicine. Like cosmonautics, space medicine was born long before its official formation.

Scientific foundations of space medicine. This new direction in medicine did not arise from scratch. Preparation for a manned flight into space took place against the background of the formation of a system of knowledge based on evolutionary and environmental physiology, the physiology of extreme states, and occupational physiology, and it was this system that formed the basis for the subsequent emergence and development of space, i.e., gravitational, physiology, which became the cornerstone of space medicine. This work was mainly carried out by the students and followers of Academician I.P. Pavlov's scientific school. As is known, cosmonautics has its own theoretician and practitioner. Regarding space medicine, we can say that the theorist was L.A. Orbeli—a representative of Pavlov's school, who was directly in charge of all issues related to human spaceflights [1]. The practitioners were aviation doctors, of the military, whose shining representative was V.I. Yazdovskii [2]. In 1947, the Institute of Aviation Medicine of the USSR Ministry of Defense was created, and the first group of young specialists came to work at this research insti-

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tute. Many of them, after decades, were rightfully called the founders of Russian space medicine.

Practical work started in the early 1950s under the leadership of S.P. Korolev with the participation of Academicians V.N. Chernigovskii, N.M. Sisakyan, and V.A. Engel'gardt, and other prominent figures of the Academy of Sciences [3]. Animals (dogs) were the first to fly into space. These studies were naturally continued on the artificial biological satellites of the Earth Sputnik 2 and Sputnik 5, which proved the fundamental possibility of a safe orbital flight of biological beings under controlled conditions and the tracking of biological functions. The first short-term human spaceflights from the point of view of the influence of the factors of outer space on the human organism were safe; however, as the duration of flights increased, the unfavorable effects of a long stay in zero gravity began to show up. This was especially evident after the 17-day flight of the crew of Soyuz 9. The tasks were posed related to the systematic study of the influence of the conditions of stay in space on the human body, with the aim of developing means and methods for preserving the health and working capacity of crew members of spaceships and stations.

As early as 1963, on the initiative of Korolev and M.V. Keldysh with the active participation of USSR Deputy Minister of Health A.I. Burnazyan, the Institute of Biomedical Problems (IMBP) was created, which had originally been called the Institute of Space Medicine, but then, for a number of reasons, it was given a broader name. The development of the Institute's research at different times was influenced by its first directors—Academicians A.V. Lebedinskii, V.V. Parin, and O.G. Gazenko. The Institute, in broad cooperation with the institutions of the Academy of Sciences and other departments and in collaboration with foreign colleagues, launched active work to study the influence of spaceflight factors on the human body.

Achievements of space medicine. The research was extensive, both in spaceflights and on the ground when simulating the conditions for the stay of cosmonauts in near-earth orbit.

The influence of the factors of orbital spaceflights on the cardiovascular system was studied by the institute's associates under the guidance of Academicians Parin, A.A. Myasnikov, and E.I. Chazov. The leading role of the movement of fluid media into the upper half of the body in the occurrence of negative reactions of the cardiovascular system to weightlessness was established [4].

Academicians Yu.V. Natochin and A.I. Grigor'ev showed the negative impact of flight conditions on kidney function [5]. This research direction made it possible to move on to another important problem, which was related to the regulation of water—salt metabolism; a whole scientific school arose. The followers of this school RAS Corresponding Members

B.V. Morukov and L.B. Buravkova and Academician O.I. Orlov with colleagues studied the problem of impaired calcium metabolism in spaceflights and the leaching of calcium from bone tissue, observed after space missions. Appropriate preventive measures were developed [6, 7]. Undoubtedly important were the results of studies of the effect of spaceflights on the respiratory system, carried out under the leadership of Academician Baranov. Significant changes in the system of external respiration and gas exchange under microgravity conditions were established; these changes lead to a decrease in the partial tension of oxygen in the blood (hypoxemia) [8, 9].

Recall the works of Academician V.S. Gurfinkel', RAS Corresponding Member I.B. Kozlovskaya, and their followers, which led to the formulation of the concept of hypogravity motor syndrome as a complex of factors that disrupt motor function in flight [10].

Of course, the implementation of the flight program at domestic orbital stations would have been impossible without research by the domestic school of psychophysiology, represented by Academicians P.V. Simonov and M.M. Khananashvili and a number of other scientists [11]. One cannot but mention space gastroenterology, founded by Academician A.M. Ugolev and his students, who developed recommendations for organizing meals for cosmonauts in relation to various flight conditions and functional states and even with account for the national characteristics of crew members [12].

In addition note life support systems, created with the active participation of not only scientists, designers, and technologists but also doctors. It was they who, with their knowledge of human physiology and reserve and adaptive capabilities, formulated the medical and technical requirements for systems that ensure a safe comfortable life and activities of crew members in the confined conditions of spacecraft and participated in tests of life support systems for compliance with sanitary standards. Regarding the life support systems for cosmonauts, note the works on biological life support systems carried out under the leadership of Academician I.I. Gitel'zon at the IMBP in Moscow and at the Institute of Biophysics in Krasnoyarsk. The results of these studies are important in the light of the upcoming tasks of deep space exploration [13, 14].

Of even greater importance for future interplanetary missions are issues of radiobiology and radiation safety. At one time, these issues were dealt with by the staff of the Biophysics Institute under the leadership of Academician L.A. Il'in [15]. At the IMBP, a laboratory with similar tasks in relation to spaceflights was headed by Corresponding Member of the Russian Academy of Medical Sciences E.I. Vorob'ev. At present, the teams of Academician M.A. Ostrovskii and RAS Corresponding Member E.A. Krasavin, as well as other scientists, are involved in studies on the possible consequences of the high radiation level beyond the

Earth's magnetic field for the health of cosmonauts. They have managed to develop a system of measures to ensure the radiation safety of manned orbital flights, which allows us to feel optimistic about the possibility of creating such a system for future interplanetary missions.

The most important achievement of space medicine during the period from Gagarin's flight to this day is the creation of a system of medical and epidemiological support for space expeditions with a duration equal to a flight to Mars and back. The cosmonaut doctor V.V. Polyakov spent almost 438 days in space. The system, which includes various means and methods of maintaining the health and working capacity of cosmonauts, is based on the knowledge gained by scientists working in various fields of basic medicine.

Space medicine and health care. The progress of space medicine was accompanied by a very important effect—practical access not only to cosmonautics but also to practical health care. We have learned to understand better the state of the physiological norm and the border between norm and pathology and to assess the functional reserves of the body and the body's response to various extreme influences. The equipment and the methods and means of prophylaxis that have been developed to monitor the health status of cosmonauts have found application in clinical medicine. In this process, an important role was played by the Academy of Sciences and its two programs: Basic Sciences in Medicine (headed by Academicians Gazenko and Grigor'ev) and Innovation and Technology Support (Academicians G.A. Mesyats and S.M. Aldoshin). These programs, mutually complementing one another, created a unified system of innovative developments from basic research to the stage of commercialization. The experience of these programs should be studied and used to expand and accelerate the processes of introducing the results in the field of space research into our life on Earth. An example of the successful implementation of the results of these programs is the introduction of the Regent suit and the Korvit device into the practice of rehabilitation of patients with neuromuscular pathology. These products are successfully used in clinics not only in our country but also abroad.

In his annual message on April 20, 2021, President V.V. Putin mentioned telemedicine as one of the important elements that had proven to be effective in the situation with the COVID-19 pandemic. Telemedicine began as a space tool. Over the years, a lot has been done, primarily by the team led by Academician Grigor'ev together with Moscow State University, the University of Medicine and Dentistry, Nizhny Novgorod University, and other organizations, to adapt space telemedicine technologies to ground-based applications. The foundations of telemedicine education have been created, and the technologies of organizational and legal support of this area of health

care have been developed [16]. Telemedicine turned out to be a toolkit that once again proved its effectiveness in the fight against coronavirus infection. The knowledge gained by space physicians in the field of physiological, physical, and psychological stress in conditions of prolonged isolation turned out to be in demand. Now this work will continue as part of a world-class center—the Pavlov Center for Integrative Physiology, which was created on the base of the Pavlov Institute of Physiology, the Sechenov Institute of Evolutionary Physiology and Biochemistry, the IMBP, and St. Petersburg Electrotechnical University.

Current challenges. At the current stage of manned cosmonautics, the attention of most scientists and designers is focused on the problem of interplanetary flights. It must be admitted that the technology of medical support for such missions will be fundamentally different from what is used now during orbital flights. First, specialists will face factors that have not been encountered before: the absence of the Earth's magnetic field, galactic radiation, etc. Second, it will be necessary to change the paradigm of preventive measures, which should become more flexible and personalized and involve the use of artificial gravity. The paradigm of medical support in the conditions of autonomous space flights should be based on the wide use of artificial intelligence, which we call among ourselves the *smart telemedicine outline*. It is necessary to create the scientific and technological groundwork for a wider application of robotic means and advanced technologies at the later stages of human expansion into space.

Of course, we must bear in mind the technologies that should be developed on the eve of the start of the program for the exploration of the Moon—exploration, not just a visit. In this regard, a number of issues require serious study, in particular, the problem of moondust. Work in this direction has already begun and must be intensified. We mean the program of participation in flights of unmanned stations to the Moon and to its surface and the BION-M program. Considering the planned changes in the federal space program, it will be necessary to correct the flight program of the BION-M 2 biological satellite, the main mission of which is a comprehensive assessment of the effect of space radiation on living organisms. Soon, we hope, the Return program (Noah's Ark) will begin to be implemented, which will allow assessing the state of biological objects after a long stay in interplanetary space. A special biological research program is being prepared for the transport ship that will fly around the Moon in the unmanned mode. The results obtained will allow specialists to assess the degree of risks and take measures to preserve the health and performance of cosmonauts during moon missions more accurately.

Let us outline in brief the International Space Station project. The biomedical part of the Long-Term

Program of Scientific and Applied Research and Experiments Planned on the ISS Russian Segment is presented in two sections: Man in Space and Space Biology and Biotechnology. They will continue until the end of the existence of the ISS, with an emphasis on advanced Russian programs. Everything that is proposed for space missions is initially investigated on earth under the conditions of complex experiments on various models.

Work on space exploration, especially in the field of space medicine, has been carried out practically from the very beginning of manned space exploration with broad international cooperation. One of the examples is the Interkosmos program, organized on the initiative and under the leadership of the Academy of Sciences and headed by Academician B.N. Petrov, within the framework of which research was carried out not only in space physics and other areas but also in space biology and medicine. Noteworthy is the Russian–American cooperation in the field of space medicine, supervised by the State Corporation Roscosmos and the Academy of Sciences on the Russian side and NASA on the American side. This work is coordinated by the Russian–American Joint Working Group on Research in Space Biology and Medicine, which turns 50 this year. Over the years, it was headed by Academicians Gazenko and Grigor'ev. Recently, the Russian party has put forward the concept of creating an international center for testing the technology of medical support for interplanetary missions. Within the framework of this concept, the SIRIUS program is being implemented, which was created by the IMBP RAS jointly with NASA with the participation of other international partners. The program is a series of isolation experiments in which scientists have already begun to develop techniques for future interplanetary flights.

Further development of space medicine technologies lies at the intersection of many sciences, and it is important not only to develop the traditional cooperation of physiologists, physicians, and biologists, which has always been a success under the auspices of the Academy of Sciences, but also the participation of mathematicians, chemists, IT specialists, physicists, and representatives of other disciplines. The role and active position of the RAS Council on Space is exceptionally important in this respect.

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