Review

History of space medicine: Academician Vasily V. Parin, founder of space cardiology

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Abstract

Russian Academician Vasily V. Parin was one of the leading world scientists in the field of physiology of blood circulation. In this article his role in the development of the space cardiology, an important area of space medicine, is considered. The development and use in space flights of such methods as the analysis of heart rate variability and seismocardiography, creation of the onboard medical equipment is connected with the name of Vasily V. Parin. The monography "Space cardiology" issued in 1967 by Vasily V. Parin with co-authors has dictated and governed the development of this key area in science for many years ahead. The article presents the basic results of cardiological researches in space in the 70-90-s and in the beginning of the 2000s when the space cardiology made its progress keeping the tendencies and traditions created by Vasily V. Parin in the 60s.

Keywords

Space cardiology • Heart rate variability • Seismocardiography • Ballistocardiography • Mars-500

Imprint

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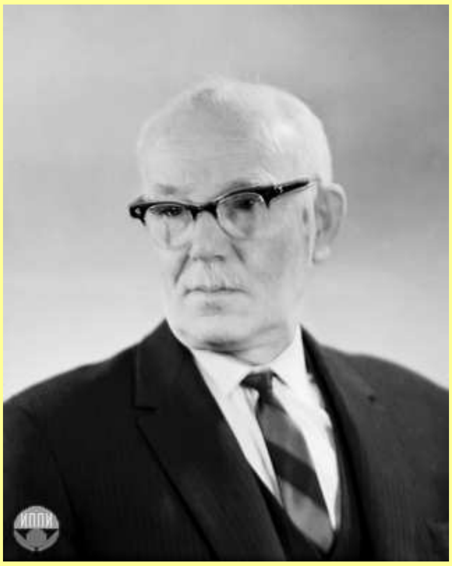

Vasily Vasilievich Parin

On the 18th of March, 2013 we celebrated the 110th anniversary of the birth of Vasily Vasilievich Parin, an outstanding Russian physiologist and one of the world-top scientists who made a great contribution to the development of blood circulation physiology. This article is dedicated to one of the principal research activities conducted by Vasily Parin, to the creation and development of space cardiology as a new research area in space medicine.

The 60s marked the beginning of the era of human space missions. The birth and rapid development of space medicine was the necessary condition for successful manned space navigation. New scientific space data on the human health effects of the space flight factors, and, in particular, the effect of weightlessness on the cardiovascular system was analyzed profoundly. In conditions of the weightless, blood is redistributed to the upper body, and the specific circulatory changes trigger various adaptive reactions in the organism. Studying the reactions resulted in the creation of a special space medical area that is known today under the name of the space cardiology.

The new space medicine area was clearly defined in the summary paper by V.V. Parin, R.M. Baevsky and O.G. Gazenko "The Heart and Blood Circulation in Space" published in Cor et Vasa in 1965. And in the same year, in 1965, the "Cardiology" Journal presented his article "Achievements and Success in Space Cardiology" considering issues of the blood circulatory system responses under adaptation of the organism to the weightlessness conditions. It has been shown there that it is just the vegetative nervous system that plays the leading role in the adaptation and that it is just the analysis of heart rate variability (HRV) as basic method that is capable of studying the vegetative regulation of blood circulation. And it was actually the space medicine that gave birth to the HRV analysis method which is now widely used in various fields of cardiology [1,2].

The first studies of vegetative regulation of blood circulation in the space flight applying the HRV analysis were performed in 1960 for dog space flights on the third earth satellite vehicle, later in 1963-64 for the Vostok -3, Vostok-5 and Voskhod-1 space flights. It have made possible to obtain valuable data in support of the suggestion that the vegetative balance shifts towards the dominance of the activity of parasympathetic regulation member at the first stage of the adaptation to the weightlessness conditions. At the 18th International Astronautic Federation Congress (1967) V.V. Parin (collaborated with R.M Baevsky and G.A.Nikulina) presented the paper "Heart Rate Rhythm as Indicator of State of Neuroendocrine Regulation of Organism in Space Flight Environment".

In 1967 the monograph "Space Cardiology" by V.V.Parin, R.M.Baevsky, Yu.N.Volkov and O.G.Gazenko was published. That work summarized a broad array of problems associated with impacts and effects of space flight factors on the circulatory system. And the cardiovascular system was presented there as an indicator of adaptive reaction of the organism as a whole. A number of essential scientific and theoretical conceptual principles determining the later development of the space cardiology were formulated there by summarizing the results of the first space flights of the Vostok and Voskhod space crafts [3,4].

The HRV analysis played the key role in studying the vegetative regulation of blood circulation in a space flight. The HRV analysis revealed the mechanisms responsible for re-configuration and re-adjustment of different vegetative regulation members under the weightlessness conditions. It has been found that first the mechanisms of the vegetative regulations are involved into the adaptation process, since the weightlessness leads primarily rather to underloading than overloading of various systems of the organism. The central mechanisms are actuated at subsequent space flight stages. A survey of the HRV analysis application cases in space medicine was introduced in a number of reports at the First All-Union Symposium on the mathematical analysis of heart rhythm guided by V.V.Parin held in Moscow, 1966. About 50 papers on the use of the above method in various areas of clinical and preventive medicine, sport and experimental physiology were discussed at that Symposium.

The analysis of cosmonaut's heart rate variability during their space flights was one of the important scientific and technical achievements in space medicine in the 60s last century. But it should be noted that almost all the components of orbit medical support system for manned space missions were developed and designed under the guidance of V.V.Parin. Salyut 1, the first orbital space station, was placed into orbit in the Parin's lifetime (April 19, 1971). The medical equipment, instrumentation and systems of that station were structurally similar to those used in the contemporary orbital stations. The medical control system was based on ECG, respiration and seismocardiogram recording. The Polynom 2M medical research equipment enabled recording of a great number of cardiac and respiratory parameters. The pioneered program design concept for on board systems was applied to in-depth medical studies and investigations. The preventive health care system was supported by a bicycle ergometer, running simulator, gravity simulating suits and a vacuum vessel to provide a LBNP chamber. It is of course clear that the current IT solutions have made a significant progress and become an integral part of the modern space ship equipment, so that the engineering capabilities which existed in the 1960s at present seems to be at least primitive. But the general principles of data acquisition, processing and analysis applied to the first manned space flights remain valid today. The past years can be regarded as the period of experience accumulation, but today we are expecting a qualitative breakthrough accompanied by a transition to a fundamentally new stage in the development of information technology in space medicine [5,6,7,8].

Our concepts of the human adaptation to the weightlessness conditions have been considerably changed and extended for more than thirty years' space science experience gained after V.V.Parin's death. The engineering systems of the manned cosmonautics have been cardinally changed, too, and now we are approaching very closely to the borderline of preparation for interplanetary missions. But the progress and achievements of the 1960s, the age of the progress made owing to V.V.Parin's academic career and organizational activity, are considered by us as the reference point for evaluating the current advances and developments in space medicine and physiology. Now we are meeting true revolutionary changes over the past three decades in the areas of space medicine and physiology which were the topics of Parin's keen interest. The case in point is the space cardiology, the use of electronics and computer-assisted equipment for monitoring and control in cosmonauts, the issues of medical prediction and medical support for long-term space missions. We would like to offer herein a comprehensive survey on the key advancements in one of the major space medicine areas which is the space cardiology that is always associated with the name of Vasily Vasilevich Parin who gained wide recognition as the founder of the said science.

In the early 80's, the space cardiology took new important steps to develop new research methods for investigations of blood circulatory system in space. A 24-h ECG recording (Holter-monitoring ECG recording) was first performed during a prolonged space flight. Thereupon, that method was included into the scope of medical continuous monitoring methods. At that time, the HRV analysis was first used in the orbital stations to asses the actual functional state of the organism during physical conditioning exercises on board.

Particular attention should be given to the method of the ballistocardiography that is capable of examining the heart contractile function by capturing pulse micro movements of the human body. It was one of the Parin's favourite methods. He pioneered in its development and application in the mid 50s in Russia, and it has been just Parin who has translated the monograph "Ballistocardiography" written by V.Dock and G.Mandelbaum from English into Russian and who has constructed the first Russian ballistocardiograph. His dream was to record a weightlessness ballistocardiogram. But it became possible only after the first orbital stations appeared, so that the first ballistocardiogram was recorded in 1977 on board the orbital station Salyut-6. But by Parin's initiative the method of the seismocardiography, closely related to the ballistocardiography, was employed already during the very first space missions.

The 90s were featured by an intensive international cooperation in the space cardiology. First of all, a collaboration project in space medicine with Austria should be mentioned, when the joint scientific experiments Pulstrans and Night were conducted on board the orbital station MIR. The experiment Pulstrans was aimed at studying vascular responses under conditions of weightlessness (recording of upper and lower limb sphygmograms). The first contactless ballistocardiogram was recorded in the experiment Night in the cosmonaut's sleep with a sensor positioned in his space sleeping bag. An extensive scientific program with Holter-monitoring ECG recording during prolonged space flights was successfully implemented in collaboration with the USA scientists. Valuable data on arterial blood pressure variability were first obtained in joint researches with scientists from France, and a baroreflex component of the weightlessness adaptation reactions was analyzed therewith. And the circadian arterial blood pressure dynamics was a subject of the joint studies as well [9,10,11].

By the early 2000s, the cardiac research results of long-term space missions on board the orbital station MIR have been summarized (R.M. Baevsky, G.A.Nikulina, I.I.Funtova, A.G.Chernikova, 2001). The activation regularities of various members in the vegetative nervous system at different stages of long-term space flights were identified. It has been shown that usually the tone of the parasympathetic regulation member is enhanced within the first two flight months. During the space flight months 3-4 noted is the simultaneous strengthening of the tone both of the parasympathetic and sympathetic systems. The space flight months 5-6 show a clear shifting of the vegetative homeostasis towards the activation of the sympathetic regulation member. A pronounced growth of the VLF (Very Low Frequency) spectral components connected with the activation of the over-segmental brain parts was observed during an extended space mission months 7-8 due to exposure to the weightlessness. Those fluctuations should be considered as a reliable indicator of the energy and metabolic process control, and they reflect energy-deficit states in the organism. The essential growth of the VLF-component of the HRV spectrum shows a development of the next adaptation stage and involving of the higher vegetative centers into the organism adaptation to the weightlessness conditions. It means that the long-term weightlessness conditions induce a supplementary mobilization of the functional resources. Results from an analysis of ultraslow (circahoralian) heart rate oscillations obtained in a super-long 14-month space mission completed by Valery Polyakov, a cosmonaut-physician, have validated the above staged-adaptation theoretical concept. The period from the 5th to the 9th months of the space flight showed the sequential activation of the higher vegetative centers with a gradual increase both in the amplitude and the circahoralian wave periods.

A new phase in the studies of the adaptation reactions of the blood circulatory system commenced with the start of the operation of the International Space Station (ISS). The emphasis was on individual evaluation of the degree of tension of the regulatory system and the functional reserves of the organism. Since 2003 the scientific experiment Pulse, the scope of which includes recording of ECG, finger photoplethysmograms and respiration rates, has been conducting on the ISS [10].

Further expansion and extension of the said experiment was undertaken in collaboration with German experts. The new Pnevmokard device was developed and designed with their participation to record an impedance cardiogram and a seismocardiogram added thereto. Since 2007 the Pnevmokard scientific experiment has been monthly performing on board the ISS that covers functional tests with fixed respiration rate, with inspiratory and expiratory breath holding technique, with an active orthostatic test before the space mission and after it (A.I. Grigoriev, R.M. Baevsky, 2007)

The Pulse and Pnevmokard experiments held within semiannual flights in 25 crew members on the ISS enabled us to produce a huge amount of scientific material on individual features of the adaptation of the cardiovascular system to long-term microgravity conditions. It has made possible to identify 4 types of the vegetative regulation differing in the patterns of their adaptation reactions. On the basis of generalization of the materials obtained therein, a mathematical model to evaluate the functional states of cosmonauts in space flights by the HRV analysis data was developed (R.M. Baevsky, A.G. Chernikova, 2002). The mathematical model allows differentiating of four types of the functional states which are as follows: the state of physiological norm, the prenosological state, the premorbid state and the pathological state. This classification of the functional states was offered in the 70-80s and enjoyed great popularity as the “Traffic Light” Rating System (Green indicates: everything is O.K.; amber indicates: attention!; red indicates: danger!). It was presented as a “status step stair”, where the level of the functional reserves (FR) was linearly connected with the degree of tension (DT) of the regulatory systems. The said mathematical model has shown that the dependence between the FR and the DT is not linear and is determined by the individual type of the vegetative regulation. Based on the described mathematical model, the probabilistic approach to an assessment of risks of pathology progression was developed. The offered new approach showed its effectiveness in analysis of the research results received from the ISS.

A new line of investigation in the space cardiology became studying of the vegetative regulation of blood circulation during night’s sleep based on contactless physiologic signal recording. Upon completion of the first experiments in this area, the new Sonocard device was designed in the 90s within the framework of the joint Soviet-Austrian scientific program, and since 2007 it has been using on a regular basis during the ISS flights. The obtained experimental materials made it possible to establish that in case of absence of day operating loading for cosmonauts there is a gradual shifting of the vegetative homeostasis towards the dominance of the sympathetic regulation member with an involvement of the above-segmentary levels of the regulatory mechanism in months 5-6 of the space flight for long-term space missions. By this means additional evidence has been furnished in support of the previously offered conclusions on the multi-stage nature of the adaptation of the organism to the long-term weightlessness conditions. Besides, the Sonocard device is also capable of assessing the quality of the cosmonaut’s sleep that is of great importance for the monitoring and control of the functional states of crew individuals, especially when they undertake high stress activities, for instance, operations in the outer space.

The development of the space cardiology is considerably promoted by ground-based experiment results where impacts and effects of space flight factors are simulated. Pioneering methodological approaches and instrumentation are tested in such experiments under conditions of long-term hypokinesia, isolation and dry immersion; the experiments of this kind reveal new factors which are utilized for elaboration of operational scientific hypothesis. So, in the experiments in 2009 with 7-day dry immersion, a novel method of evaluation of myocardial energetic and metabolic processes, namely, the dispersion ECG mapping was verified. It was shown there that the redistribution of blood and water-electrolytic shifts in the organism cause changes in the electrophysiological characteristics in the myocardium. Those data were utilized for the scientific justification for preparation for new special experiments on the ISS (the Cosmocard experiment).

A large series of cardiologic tests were included into the Mars-500 experiment simulating the space mission to Mars. For the said project used was the complex of cardiologic methods and techniques (the Ecosan-2007 device), that was applied to monitoring and control in 6 individuals of the international crew under conditions of the 520 day isolation and confinement in a sealed ground-based simulation facility, accompanied by the similar monitoring and control of 10 reference groups (each consisting of 10-15 subject) in different parts of the world. The huge experimental database resulted from the project in question enables us not only to prepare medical and technical requirements for the future interplanetary space ship equipment and refine our understanding of the issues on the physiological norm and transitional states, but to offer also the scientific justification of innovative methodology and equipment intended for use in space researches and health care.

An introduction of space technologies in the health care practice has always a significant place in the space cardiology. As early as in the 80s, the Autosan-82 lab as a portable automated laboratory was designed for preventive health examinations of population. The lab was equipped with the devices and applied the methods which were identical to those utilized in the Salyut-6 orbital station. Besides, there a medical computer was provided that was absolutely exclusive in its space medicine application. At the beginning of 2000s, the Stressmeter clinical device based on the Pulse device was created, and commercial production of the Varicard HRV analysis device was started. Before its space application, the Ecosan-2007 complex mentioned above had successfully completed clinical and physiological trials and tests in health examinations of bus drivers and civil pilots. The space device Sonocard was a pilot product for the development of its Earth-used analogue, namely, the device Cardioson-3 that is capable of conducting contactless investigations of sleep that is of great importance for critical patients in intensive care units.

So, the space cardiology, a new research area, born in the 60s, has been making a good progress in the context of space medicine, in a close cooperation with the conventional clinical and preventive cardiology. In this case, the innovative nature of the space cardiology progression should be noted. It applies the latest and the most advanced scientific achievements modifying them in order to solve its specific issues. Innovative original concepts and solutions of methodical and scientific problems are intensively conveyed for their use to conventional health care practice and applied physiology. Such doubled feedback promotes further successful advancements of the space cardiology as a separate area in science and practice.

Conclusions

The space cardiology is a new research area that was formed in the 60-70s last century under the guidance of V.V. Parin and that demonstrates its intensive development nowadays. In 2011, within the framework of 14th Congress of the International Society for Holter and Noninvasive Electrocardiology (14-th ISHNE, Moscow, 2011), a special symposium on space cardiology was held, which was dedicated to the 50th anniversary of the first human space flight. 8 reports on top priority issues of the space cardiology were presented at the symposium. Their publication is devoted to the 110th anniversary of Russian Academician Vasily Vasilevich Parin, the founder of the space cardiology, the contemporary advancements of which are intimately linked with the name of the Russian prominent scientist.

Statement on ethical issues

Research involving people and/or animals is in full compliance with current national and international ethical standards.

Author contributions

All authors prepared the manuscript and read the ICMJE criteria for authorship. All authors read and approved the final manuscript.

Conflict of interest

None declared.

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