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ANALYTICAL REVIEW AND SYSTEMATIZATION OF DATA FROM PROSPECTIVE STUDIES RELATED TO THE EXAMINATION OF THE FUNCTIONAL STATE OF THE CARDIORESPIRATORY SYSTEM OF ASTRONAUTS

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Key words: astronauts, space flight, adaptation, cardiovascular system, hemodynamics, respiratory system, hemic system.

Annotation. The purpose of this study was the analytical review and systematization of data from prospective studies related to the examination of the functional state of the cardiorespiratory system of astronauts. Results of the theoretical study show that the conditions of zero gravity and gravitational loads during space flight cause significant physiological changes in the cardiorespiratory system of astronauts. There are changes in the cerebral, central and regional hemodynamics, a shift in the type of blood circulation towards the hyperkinetic type. Unfavorable disorders on the part of the ankle veins, consisting in an increase in capacity and extensibility, were revealed. The negative influence of the detrained cardiovascular system on the orthostatic tolerance of astronauts is shown, which is recommended to be used as a significant parameter of the functional state of the organism. The study of heart rhythm variability under the influence of space flight factors makes it possible to predict the probability of the transition of the functional state of the astronauts' organism from the state of physiological norm to the pre-nosological or premorbid state. At the present moment, the influence of space flight factors on the functional state of the respiratory and hemic systems, as well as the features of post-flight recovery of these systems, is insufficiently studied.

Introduction. Work of astronauts is considered as an extremely hard activity, related to significant emotional, mental and physical loads within the background of constant exposure of such specific factors of space flight (SF), as zero gravity, gravitational loads, radiation exposure, vibration, hypokinesia, conditions of closed environment, isolation. All of this lead to significant functional and morphological changes, which should be considered as the adaptation process. Decrease in gravity exposure in conditions of space flight has an effect on almost all physiological systems of a human. The cardiorespiratory system is the system, which is most exposed to SF effects [10, 17, 18, 19, 20, 22]. Therefore, the conducted theoretical study is relevant.

The study was carried out in compliance with the state task of the FSBI "NCSCC of the FMBA of Russia" to develop the applicative scientific project named "Development of new scientifically based methods and programs of the second stage of post-flight medical rehabilitation of astronauts in spa conditions", classification number: "Astronaut rehabilitation 21/23".

The purpose of this study was the analytical review and systematization of data from prospective studies related to the examination of the functional state of the cardiorespiratory system of astronauts.

Methods and organization. The method of content analysis of literature sources of Russia-based and foreign researchers. Articles, included in Google Scholar and RSCI, were analyzed. Twenty-three sources were selected and analyzed.

Results and discussion. Results of the theoretical analysis show that in zero gravity conditions of SF, the hydrostatic pressure of blood and other body fluids decreases to zero, which leads to substantial changes in the cardiovascular system (CVS). As a result, an increase of blood volume and blood pressure in head vessels, stretching and stimulation of mechanoreceptors of atriums and the pulmonary vascular bundle, which, in return, contributes to the activation of reflexory and humoral mechanisms aimed at the preservation of hemodynamic and water-salt homeostasis" [13].

Urgent compensation and adaptation responses are aimed at the suppression of secretion of the antidiuretic hormone located in the hypophysis with a decrease in activity of the renin-angiotensin-aldosterone system and the suppression of the vasomotor center. It leads to partial loss of fluid and electrolytes by the increase in frequency of diuresis decrease in the blood plasma volume, reflexory coarctation of lung vessels, extension of vessels of the central circulatory system, stagnation of blood circulation in internal organs and limitation of blood flow to the cardiopulmonary area. In later periods of staying in zero gravity conditions, adaptation responses start appearing, which are manifested through the decrease in the total volume of red blood cells' mass and hemoglobin, leading to the further decrease in the volume of circulating blood. In conditions of zero gravity, the blood shift to the upper part of the body is manifested through sensations of rush of blood to the head, extension of head vessels, presence of dull pulsating pain in the head, puffiness of face and neck skin, swelling of neck veins and the congestion of sclera vessels [13].

Observation and analysis of the functional state of the CVS of the group of astronauts, who took long-term space flights (125 to 438 days) on the "Mir" orbital complex at rest (279 before the flight and 234 after the flight) allowed researchers to divide the CVS's functional state in accordance with the cardiac index value into three types of blood circulation. A dependence of the blood circulation type on genetic factors, age and conditions of study management (at rest and before functional tests) was established. The research data has shown, that during space flights, intensification of the chronotropic function of the heart, increase in the cardiac output (CO), increase of the end-systolic blood pressure (ESBP) in arteries and systolic blood pressure in the lung artery are registered in astronauts. Before functional testing, the hyperkinetic blood circulation (HBC) was identified. However, values of defined indicators did not exceed limits of the age-related physiological norm. During the detailed analysis, three types of responses to micro-gravity conditions were revealed. The CO increase (on account of the stroke volume and heart rate) was accompanied by the increase in ESBP. Significant changes in ESBP were not registered in case of the decreased volumes of hemocirculation and the eukinetic blood circulation (EBC). No significant changes of all examined indicators were found in some astronauts [2].

Researchers put a great emphasis on features and types of blood circulation in astronauts, pointing out the fact that individuals with different types of blood circulation have a various response to micro-gravity conditions, as well as to the dosed physical load before and during the flight [14].

Authors note that for the whole examined group of astronauts at rest the vector of distribution of blood circulation types shifted from EBC to HBC with a decrease of hypokinetic blood circulation (HypoBC) and EBC. During and after dosed physical loads on a stationary bicycle in case of all blood circulation types, features, typical for micro-gravity conditions, were revealed: absolute values of the stroke volume (SV), CO and SBP were less than before the flight in the same conditions; the growth rate of HR, CO and SBP was decreased. In case of HypoBC, the growth rate of SV was decreased, in case of EBC and HBC, its reaction was changed. In case of all blood circulation types, the CO formation mechanism was changing. In order to support the needed level of SBP, pressor vascular responses played a leading role [14].

Alongside with the shift in the blood circulation type in SF conditions, experts also note a notional effect of the blood circulation type on tolerance and functional responses of the CVS to physical loads on the stationary bicycle in astronauts, who took long-term (73 to 438 days) SF on the "Mir" orbital complex, during the functional test with a dosed physical load on the stationary bicycle (two-phase, with a power of 1150 W and three-phase, with a power of 1350 W). It was revealed that in case of both types of physical loads before the flight, the reaction was less favorable for HBC. In these cases, the CO increase was supported by the dominating impact of the chronotropic function of the heart. In case of HypoBC and EBC, the response to loads was close to normal. In conditions of micro-gravity of the SP and in case of any blood circulation type and loads, the CO increase was made by a less effective physiological mechanism, which is a HR increase, explained by the insufficient venous return [1].

According to data of the occlusive plethysmography, conducted in the state of zero gravity, it was revealed that following indicators of central hemodynamics remain at rest: cardiac pump function, blood supply of the brain, BP and HR. However, the tolerance of regional arterial vessels was decreased below the heart level. More profound changes of venous hemodynamics were identified: slow-down of venous return, decrease in the resistance of vessels of the lower part of the body, increase of the legs venation capacity. During functional testing with an exposure to the negative pressure of the lower part of the body (NPLPB), a worsening of gravity-dependent reactions, which progressed with an increase of SF duration, was revealed. Therefore, the unclaimed anti-gravitational distribution of the vascular tone disappeared in zero gravity conditions. When returning to conditions of Earth gravity, phenomena of the detrained CVS were registered, manifested by the decrease of tolerance to loads at the stage of coming down from the orbit and the orthostatic instability within the post-flight period [9].

Further research, conducted by experts, allowed identifying 3 degrees of changes in the deficit of the cerebral blood flow when identifying the orthostatic tolerance (OT) to zero gravity during testing with the NPLPB exposure. Authors note that dynamics in changes of arterial hemodynamics' response to the NPLPB exposure allowed evaluation not only the state of OT at the moment of study, but also the tendency of changes in OT during the flight, which indicates a possibility of individual prognosis of changes in OT of an astronaut during SF. Three stages of changes in informative indicators of the state of lower extremities' veins were identified: capacity, elasticity and speed of repletion. These data allow predicting various degree of OT decrease [10].

Observation of the state of ankle hemodynamics in astronauts during the short-term (less than 1 month OT) SF showed a decrease in tolerance to the NPLPB exposure during the flight, which was manifested further by a decrease in the post-flight OT during active and passive orthostatic testing. Authors explain these changes by a decrease in the vasoconstrictive capacity of magistral arteries of lower extremities and an increase in elasticity of leg veins. These data are recommended to use for making an individual prognosis of the post-flight OT [16].

Studies on the state of veins of lower extremities of astronauts, which were carried out by the same experts in case of 6-month SF, revealed changes, related to a decrease in ankle volume of all astronauts and a significant increase of the vein capacity and elasticity. Changes in speed of ankle vein repletion were differently directed: decrease in blood content was revealed in 74% of astronauts, 16% had an increased blood content. Researchers concluded that in SF conditions, changes in veins of lower extremities could be one of the pathological mechanisms of OT decrease [7].

Comprehensive study on the state of veins and venous hemodynamics before, during and after 6-month SF revealed a profound dilation of magistral veins in head and neck, abdominal organs and lower extremities during the whole time of staying in zero gravity conditions. Dilation in hip veins had a tendency to increase during the whole period of SF. An increase of elasticity and compliance of ankle veins was registered during occlusive tests at the beginning of the flight (1-2 week). [15]

Studies on the state of ankle veins during annual SF. During the first half of the yearlong SF, an increase of capacity and elasticity of veins was registered; the profoundness of changes was individual. The profoundness of changes in capacity, elasticity and speed of repletion of ankle veins of astronauts in the second half of the yearlong SF was also individual and notable for the absence of stability; all these changes also had an unfavorable nature in relation to OT. Recovery after the yearlong SF to the pre-flight level of the state of ankle veins was slower than recovery after 6-month SF. Complete recovery was not achieved even after 8 days of the post-flight period. [8]

A connection between physiological responses of astronauts when exposed to overloads in the area of going down from the orbit to Earth with changes in blood flow in conditions of short-term zero gravity was identified by researchers. It was revealed that astronauts with a profound decrease in cerebral blood flow during testing with NPLPB in SF showed signs of worsened cerebral blood flow in form of dizziness, weakness and hyperhidrosis after landing when taking a vertical position and leaving the descent vehicle. In astronauts with a profound increase of the tone of arterial and venous vessels in zero gravity conditions with a following effect of overloads, internal hemorrhage in the back skin cover were registered [6].

Issues of health and longevity remain relevant from the point of SF physiological effect on the CVS of astronauts. Specially conducted studies show that prevalence of cardiovascular diseases in the age of 60 is on the high level among astronauts, who ended their professional activity. It is also important to note that in the age over 60 years, every second athlete has an increased level of BP, every fourth – an increased level of cholesterol. Furthermore, a tendency of an increase of the arterial hypertension (AH) prevalence is registered in 99-100% of astronauts in the age over 60 years, dyslipidemia – in up to 66% of astronauts and, consequently, the coronary heart disease (CHD) is registered in 40% of astronauts. In senile age (over 80 years), in all patients, AH and CHD are registered, every third has a cerebrovascular disease. Among astronauts, who ended their professional activity, the AH prevalence corresponds to statistical data in Russia, the CHD is registered in senile age (over 70 years), among men in Russia the CHD is registered in the age of 55 years and older. It is possibly due to the fact that the medical selection for a crew of astronauts is made from the group of people with the best state of health [5].

Analysis of the results of studies of astronauts with different types of vegetative regulation has shown that the first, second and the third month of the flight appear to be critical to astronauts with a vagotonic type of regulation due to strong oscillations in the balance of sympathetic and parasympathetic effects in the heart rhythm regulation. The second month of the flight differs by an increase of the vagal activity, which can be accompanied by dysregulation disorders with a prevalence of parasympathetic nervous system. In astronauts, who has a sympathicotonic type of regulation, a RMSSD (root mean square of the successive differences) indicator begins to decrease, which shows the weakening of the parasympathetic activity.

Recent studies on the heart rhythm variability in athletes showed that functional loads, based on a decrease in functional reserves of an organism in zero gravity conditions, depend on an individual functional reserves of an organism in conditions of zero gravity, which are gradually depleted during SF. Loads of the functional state are increasing alongside with the duration of SF. [3]

SF factors also reflect on the functional state of the respiratory system of astronauts; however, the number of studies, which examine this issue, is small. The study on features of the voluntary management of respiratory movements in conditions of the long-term space flight showed an individual destabilization of systems during the transition from earth-based conditions to space conditions and vice versa [12].

Functional state of the respiratory system, as well as the blood circulation, is defined by a duration of an impact made by SF factors. Studies show that a month of staying in SF conditions is accompanied by multidirectional changes, characterizing voluntary respiratory movements, which do not stabilize within 30-34 days [12].

After the 10-180 day SF, a stabilization of speed- and precision-based spirokinographic indicators on the new functional level happens. Return of astronauts to the earth-based conditions (14 days) is accompanied by multidirectional changes in spirokinetic parameters. Observed in the first month of SF negative correlation between the latent period of a response and respiratory movement speed, which is not typical for a steady state, was registered [12].

Experts have also revealed a change in state of the respiratory center in zero gravity [12, 21]. The level of activity of the central respiratory mechanism was evaluated during the 340-day expedition on the International Space Station. An increase was registered in the time of breath holding during the post-flight period, in comparison with the pre-flight period, by 22% on exhale with NPLPB and 13% at rest. These data indicate a decrease in the activity of the central respiratory mechanism in conditions of zero gravity of the long-term SF, which could be a consequence of blood redistribution to the upper part of the body [4].

The number of studies, considering the examination of biochemical blood indicators in astronauts, is very small; however, the already present data show, that Russian astronauts are characterized by different levels of their reference values in comparison with average ones. Limits of reference values of blood indicators in astronauts are narrower than average approximate ranges. It was revealed for such indicators, as the total and pancreatic amylase, glycated hemoglobin, leucine aminopeptidase, lactate dehydrogenase, creatine phosphokinase, total and pancreatic lipase, uric acid, total protein, oxybutyrate dehydrogenase, pyruvic acid, high-density cholesterol lipoproteins, total and bone alkaline phosphatase. Experts connect these differences to features of the astronaut selection, as well as the special physical fitness and psychoemotional state of crewmembers [11].

Conclusion. Therefore, zero gravity conditions and gravitational loads during SF cause significant physiological changes in the cardiorespiratory system of athletes. Changes in cerebral, central and regional hemodynamics were registered both at rest and with dosed physical loads. During SF, a change in the type of blood circulation into the HBC was also registered, which could be the reason for AH. Experts gave the most attention to the study on the effect of zero gravity on the functional state of vessels of lower extremities, ankle vessels in particular. Unfavorable disorders of ankle veins were identified, including the increase in their capacity and elasticity, which decreases the venous return to the heart, especially in case of loads. Studies showed the negative effect of the detrained CVS on the OT of astronauts, which is recommended for using as a significant parameter of the functional state of an organism. The use of heart rhythm variability under the influence of space flight factors makes it possible to predict the probability of the transition of the functional state of the astronauts' organism from the state of physiological norm to the pre-nosological or premorbid state. However, when using it, it is important to take into account functional reserves of the organism and the individual type of vegetative regulation. At the present moment, the influence of space flight factors on the functional state of the respiratory and hemic systems, as well as the features of post-flight recovery of these systems, is insufficiently studied.

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