АВИАЦИОННАЯ, КОСМИЧЕСКАЯ И МОРСКАЯ МЕДИЦИНА / AVIATION, SPACE AND MARINE MEDICINE

DOI: https://doi.org/10.23670/IRJ.2022.126.35

THE EFFECT OF STEROID HORMONES ON PHYSIOLOGICAL PARAMETERS AND HUMAN BODY COMPOSITION DURING SHORT-TERM SIMULATION OF SPACE FLIGHT FACTORS

Research article

Nichiporuk I.A.[1,]*, Chistokhodova S.A.[2], Vorontsov A.L.[3]
[1] ORCID : 0000-0003-0118-3374;
[2] ORCID : 0000-0003-2915-8090;
[1, 2, 3] Institute of Biomedical Problems of the Russian Academy of Sciences, Moscow, Russian Federation

* Corresponding author (igor.nichiporuk[at]yandex.ru)

Abstract

The main purpose of the present research was to analyze the interrelationships of steroid hormones with physiological parameters and human body composition during short-term simulation of space flight factors combined with or without the use of countermeasures, in particular, in studies involving healthy male volunteers in 21-day dry immersion, in 24-hour exposure to hypogeomagnetic field, as well as at investigating the effects of physical training or their absence in 14-day isolation of two mixed crews (3 men and 3 women each).

The results of studies in dry immersion indicate the relationship of steroid hormones with parameters of hemodynamics and body composition, which have a positive impact in men of more mature age and contribute to their better adaptation to a complex of influencing factors.

It is shown that the decrease in the intensity of the geomagnetic field initiates an increase in lean body mass and oxygen demand at rest accompanied by the decreased steroid secretion and respiratory coefficient – the development of characteristic adaptive reactions to the effects of extreme environment.

The results of complex studies in conditions of short–term isolation revealed the adverse effect of intensive physical training and the involvement of mineralocorticoids and androgens in the regulation of the componential composition of the lower extremities – highly important constituent of the musculoskeletal system of a modern human – the descendant of “Homo erectus”.

Keywords: steroid hormones, dry immersion, isolation, hypogeomagnetic field.

ВЛИЯНИЕ СТЕРОИДНЫХ ГОРМОНОВ НА ФИЗИОЛОГИЧЕСКИЕ ПОКАЗАТЕЛИ И СОСТАВ ТЕЛА ЧЕЛОВЕКА ПРИ КРАТКОВРЕМЕННОМ МОДЕЛИРОВАНИИ ФАКТОРОВ КОСМИЧЕСКОГО ПОЛЕТА

Научная статья

Ничипорук И.А.[1,]*, Чистоходова С.А.[2], Воронцов А.Л.[3]
[1] ORCID : 0000-0003-0118-3374;
[2] ORCID : 0000-0003-2915-8090;
[1, 2, 3] Институт медико-биологических проблем Российской академии наук, Москва, Российская Федерация

* Корреспондирующий автор (igor.nichiporuk[at]yandex.ru)

Аннотация

Основной целью настоящего исследования был анализ взаимосвязей стероидных гормонов с физиологическими параметрами и составом тела человека во время кратковременного моделирования факторов космического полета в сочетании с использованием контрмер или без них, в частности, в исследованиях с участием здоровых добровольцев мужского пола в 21-дневном сухом погружении, в 24-часовом воздействии гипогеомагнитного поля, а также при исследовании последствий физических тренировок или их отсутствия в 14-дневной изоляции двух смешанных экипажей (по 3 мужчины и 3 женщины в каждом).

Результаты исследований в условиях сухой иммерсии указывают на взаимосвязь стероидных гормонов с параметрами гемодинамики и составом тела, которые оказывают положительное влияние на мужчин более зрелого возраста и способствуют их лучшей адаптации к комплексу влияющих факторов.

Показано, что снижение напряженности геомагнитного поля инициирует увеличение мышечной массы тела и потребности в кислороде в состоянии покоя, сопровождающееся снижением секреции стероидов и дыхательного коэффициента – развитием характерных адаптивных реакций к воздействию экстремальной окружающей среды.

Результаты комплексных исследований в условиях кратковременной изоляции выявили неблагоприятное влияние интенсивных физических тренировок и участие минералокортикоидов и андрогенов в регуляции компонентного состава нижних конечностей – важнейшей составляющей опорно-двигательного аппарата современного человека – потомка «Homo erectus».

Ключевые слова: стероидные гормоны, сухая иммерсия, гипокинезия, изоляция, гипогеомагнитное поле.

Introduction

The effect of steroid hormones on the state of metabolism under the influence of microgravity and other factors of space flight (SF) is the subject of the constant attention of researchers due to their important role in the regulation of physiological functions, the state of muscle and bone tissues, reproductive system, psychophysiological status, immunological reactivity and energy exchange in the organisms of cosmonauts and astronauts, which is important especially in the light of the prospects of interplanetary flights and the construction of on-planetary structures for long-term stay of people in them due to increased radiation and decreased magnetic field [1], [3], [4], [5].

Under SF conditions, glucocorticoids play a serious role in changing body composition, especially in reducing muscle mass and altering metabolism. In particular, protein biosynthesis modified even in short-term SF, which could be due to the development of stress confirmed by the increased urinary excretion of cortisol in Apollo 17 crew members under the high psychophysiological loads [1]. Changes in steroid hormones were noted during the period of acute adaptation to SF conditions in cosmonauts and astronauts exposed to space motion sickness, prolonged exposure to a complex of SF factors led to changes in the circadian rhythms of free cortisol secretion [1]. Changes in aldosterone in most cases were due to the involvement of the renin-angiotensin-aldosterone system (RAAS) in response to shifts in body fluids and water-electrolyte homeostasis [1], [2].

The dynamics of testosterone is given great importance of the other steroids in SF conditions. In early studies a decrease in testosterone blood concentrations in short-term SF on the Space Shuttle transport spacecraft was shown, a decrease in testosterone levels in blood serum and urine was revealed in rats after the flight compared to the initial data [1], [2], [4]. However, more recent studies of the dynamics of total, free and bioavailable testosterone, dehydroepiandrosterone and dehydroepiandrosterone-sulfate in the conditions of short-term flights of American astronauts on the Space Shuttle, in long-term SF on the International Space Station, and also in 30-90-day antiorthostatic hypokinesia (ANOH) have revealed that the concentrations of androgens during SF and hypokinesia practically did not change, and a decrease in blood testosterone was observed only in the early recovery period [5]. No detailed research focused on dynamics of estrogens in male crew members were conducted under SF conditions, single studies in the field of sex steroids in female astronauts were aimed at evaluation the risk of hemostasis disorders' occurrence when they had intakes of combined oral contraceptives during SF [6], [7].

In simulating experiments with ANOH, isolation in hermetic chambers and in dry immersion (DI) studies of steroid hormones are aimed mainly at assesses the severity of stress and changes in RAAS and hemodynamics [8], [10], [14], [17]. Special attention is paid to testosterone in combination with physical exercises as a possible promising countermeasure against adverse changes of the musculoskeletal system [18].

In our studies with long-term ANOH, short-term and long-term isolation, changes in body fluids, body composition and metabolic parameters were revealed indicating the development of hypohydration and hypovolemia of the body accompanied by the activation of steroidogenesis in the adrenal cortex, increased aromatization of androgens into estrogens mainly in men (except for long-term ANOH) accompanied by a decrease in the activity of the thyroid system, while maintaining absolute and specific resting energy expenditure, increased risks of fertility disorders, in general, indicating that steroid hormones are significantly interrelated and regulate changes in physiological functions and body composition via the ratio and balance of catabolic and anabolic reactions under extreme exposures [14], [16], [17], [19]. However, a systematic analysis of the results of the complex experimental ground-based simulating studies of the effects of steroid hormones on physiological parameters and human body composition including countermeasures against adverse manifestations that contribute to understanding the mechanisms of regulatory reactions involving steroids on the componential composition of the body is insufficient which led to the realization of the present research devoted to assessing the relationship of steroid hormones with physiological indicators and body composition during short-term simulation of SF factors.

Aim, objectives and methods of research

The main aim of the present research was to analyze the interrelationships of steroid hormones with physiological parameters and body composition during short-term simulation of SF factors combined with the use of countermeasures or their absence.

The research objectives included:

1. Analysis of changes and evaluation of the relationship of steroid hormones with physiological parameters and body composition in conditions of 21-day dry immersion.

2. Analysis of changes and evaluation of the relationship of steroid hormones with physiological parameters and body composition in conditions of 14-day isolation with and without physical exercises.

Additionally, an analysis of changes and an assessment of the interrelationships of steroid hormones with physiological parameters and body composition were carried out under conditions of short–term exposure to a hypogeomagnetic field – a factor that will have an exceptional effect on the human body in planned interplanetary flights [2], [20].

Anthropometric parameters – height and body mass (BM) were measured by medical scales VMEN -200-50/100- D1-A-"Norm-4" with a mechanical height meter RP (Russia), hemodynamic parameters of examined volunteers – heart rate (HR), arterial systolic (APs) and diastolic (APd) pressures were recorded using an automatic pressure meter PRO-35 from B. Well Swiss AG (Switzerland); minute volume of blood circulation (cardiac output, CO) was calculated by Liljestrand and Zander method [21].

The values of body composition's components – the volume of total body water (TBW), extracellular (EXCF) and cellular (CF) fluids, lean (LBM) and fat (BFM) body masses, the resting energy expenditure (REE) were automatically calculated by the software of the multifrequency device "SPRUT-2" (STC "MEDASS", Russia) during bioelectric impedance analysis and bioelectric impedance vector analysis using 5 and 200 kHz scanning signals, 5 pairs (potential and recording) of disposable electrodes placed on forehead (above pupils), 1 cm proximally of radiocarpal joints and ankles [22], body cell mass (BCM), dry lean body mass (DLBM), intracellular substance (ICS) and body mass index (BMI) were calculated manually during data processing [22], [23].

Indirect calorimetry and spirometry methods (portable gas analyzer BH-4S, Henan Bosean Electronic Technology Co. Ltd.; spirometer SpirOxP, Meditech Equipment Co. Ltd, China) were used for the registration parameters of microclimate, respiratory system, respiratory function and energy expenditure.

Measurement of neurohormonal parameters by enzyme immunoassay (EIA) – the concentrations of hormones in blood serum and saliva samples was carried out using commercial test-kits of DBC and Monobind Inc. (Canada) by equipment of Bio-Rad Inc. (USA).

21-day dry immersion

The studies with a 21-day DI involved 10 healthy male volunteers who signed informed consents to participate in the experiment. The program of the experiment was approved by the Commission on Biomedical Ethics of the SSC RF – IMBP RAS 03.08.2018, Protocol No. 483. The DI series consisted in 5 subseries with simultaneous participation (with 1 day difference of start-end) of two subjects in two separate baths with thermoneutral maintained water temperature 32,2±0,2 °C (hereinafter mean ± standard error of mean) and with total out-of-bath time for hygienic procedures 23,2±1,1 minutes per day including 1,8±0,3 minutes in upright position. The anthropometric parameters (age, height, BM, BMI) of the test-subjects were recorded during the studies. The measurement of hormones – concentrations of cortisol, total and free testosterone and estradiol was carried out by EIA methods in venous blood serum samples taken in the morning on an empty stomach before and during DI (7 and 21 days).

14-day isolation

The research was carried out in the ground-based experimental building (“NEC”) of SSC RF – IMBP RAS consisted of communicating hermetic chambers 100 m^3 (medical module), 150 m^3 (residential module with separate cabins for each subject) and 250 m^3 (household module – only for the group with countermeasures). The subjects of the study were healthy volunteers aged 34,3± 2,2 years – the crew of the international 17–day experiment with isolation in hermetic chambers "SIRIUS-17" (three men and three women) without the use of countermeasures. The experiment program was approved by the Commission on Biomedical Ethics of the SSC RF – IMBP RAS on 23.10.2017, Protocol No. 460.

In the same series of studies, data of 6 volunteers who underwent medical and psychological selection and signed Informed Consents – their initial period of 120-day isolation in the SIRIUS 18/19 experiment were used (3 men aged 38,2±1,9 years and 3 women aged 30,3±0,7 years). The program of the experiment was approved by the Commission on Biomedical Ethics of the SSC RF – IMBP RAS 18.02.2019, Protocol No. 501. This group of subjects used physical exercises on special devices (treadmill with passive and active loads, exercise bike, expanders, and vibration trainer) as a countermeasure. It should be noted that all test-subjects voluntary have exceeded the recommended amounts of physical exercises.

The data analysis included the results of anthropometry, bioimpedance measurement and the concentrations of aldosterone, total cortisol and testosterone in the morning blood serum samples measured by the EIA method.

Research in the hypogeomagnetic field

The studies consisted of 3 sessions: a basal data collection (background), a placebo session and a hypogeomagnetic field (HGMF) session, the choice of sessions for 8 healthy male volunteers aged 26 to 44 years was random (the method of "blind control"). The research program was approved by the Commission on Biomedical Ethics of the SSC RF – IMBP RAS 11.05.2020, Protocol No. 542; all volunteers signed informed consent to participate in the experiments. Each participant underwent a 4-hour training session in the “ARFA” (Harp) simulation unit, then stayed in it twice for 24 hours with breaks (8 hours of exposure, 15-30 minutes break): under normal geomagnetic field conditions (placebo) and – HGMF (attenuation coefficient 500). The interval between sessions was 7-14 days. All examinations and blood collection were carried out in the evening based on the time of exit of the test-subjects from the installation "ARFA" – 19:00-20:00. Anthropometric and hemodynamic parameters were recorded in all subjects, body composition indicators were measured during bioelectric impedance analysis and bioelectric impedance vector analysis. In each session indicators of the respiratory system, respiratory function and energy expenditure were measured using indirect calorimetry and spirometry. Concentrations of aldosterone, total cortisol, estradiol, progesterone, dihydrotestosterone (DHT), free testosterone and free cortisol (in saliva) were measured in blood serum and saliva samples by EIA.

The mode of work and rest in all experiments provided for an 8-hour night sleep and a 16-hour daytime wakefulness (in the supine position in DI, reclining – in a series with HGMF), 3 meals a day based on a lifestyle with moderate physical activity (total energy requirement = REE * 1,7), water intake was not limited but registered [2].

The experimental data were processed using statistical analysis methods using the application programs Statistica for Windows v. 7.0 and SPSS v.12.0 (StatSoft, Inc. and SPSS Inc., USA) [24]. The median (during the median test), means, their standard deviation and standard error of mean (S.E.M.) were calculated. To assess the reliability of the differences (p) between the samples, the parametric Student t-test or nonparametric Kolmogorov-Smirnov and the median tests were used. The relationships of the variables were determined by parametric linear correlation analysis using the Pearson coefficient (r), as well as multivariate statistical analysis – multiple regression with sequential addition of variables (“forward stepwise”) [24].

Main results and discussion

Relative indicators were used when analyzing the array of variables in addition to the absolute values – individual data in the form of a percentage of the initial (background) values to leveling differences in indicators and correct comparison, especially in series with the mixed crews (both genders) with a wide range of minimal and maximal limits of the physiological norm (for example, blood concentrations of aldosterone and cortisol).

The results of the DI studies are presented in Tables 1 and 3. All the indicators determined before and during the DI period were within the physiological norm. The effect of DI factors (support unloading, decrease in proprioceptive afferentation, decrease in locomotor activity, redistribution of body fluids) led to the significant decrease in body mass, BMI and CO in the test-subjects, accompanied by an increase in blood concentrations of all measured steroid hormones (Table 1). This orientation of the observed changes is consistent with the results of the complex impact of DI factors, in particular, the conditionality of the relationship of the blood plasma circulating volume (VCP) with the redistribution of fluid into the blood vessels from the interstitial and intracellular spaces of the superficial and adjacent tissues of the body (skin, leg and trunk muscles) due to their constant compression by water of immersion bath through a special film on which the test-subject is situated. This enlargement of VCP accompanied by periodic removal of fluid "excess" by the kidneys is resulted in the development of a negative water balance, since increased VCP reduces a thirst. Such a "cycle" of fluid shifts in DI is confirmed by the studies of the dynamics of VCP in DI [10], [12], and in the present research – by the changes in hemodynamic parameters and steroids affecting kidney function. It should be noted that no significant changes in blood concentrations of total proteins, albumin, globulins [17] and, especially, the partial water balance (Table 1) were found in the present DI research, evidently, due to the calculation of the total water intake (all beverages and food) comparing to the incomplete water intake (beverages and soup only) calculated in the reported DI studies [12], [13]. The final stage of the research in DI was a multiple correlation analysis of an array of experimental data (20 cases x 13 variables) in which the dependent variable was the relative values of BMI (% to background level). The results are presented in Table 3. Interpretation of the table data shows that in more than 99% of all cases the decrease in BMI under DI conditions was observed in more mature subjects and was associated with the increases in APd and CO, higher blood concentrations of total cortisol, aldosterone and a shift in the ratio of total/free testosterone towards the free fraction.

At the same time, the ratios of the cortisol/testosterone and estradiol/testosterone total fractions indicate a shift in the catabolism-anabolism balance towards an increase in the activity of anabolic processes in the body and a decrease in the aromatization of androgens into estrogens in individuals with a decrease in body mass index values, which, in general, should be assessed as a positive orientation of adaptive reactions to the effects of a complex of DI factors.

The results of the studies in the HGMF are presented in Tables 2 and 3. All the determined indicators in the series with placebo and during the period of exposure to HGMF were within the physiological norm. The analysis of the mean group values of the determined indicators did not reveal any significant changes. The use of parametric and nonparametric methods of linear correlation analysis also did not show significant correlations of absolute and rank estimates of geomagnetic field with variables of the entire complex of studied parameters, which initiated the use of multiple correlation analysis of an array of experimental data (16 cases x 14 variables) where the dependent variable was "the rank level of the geomagnetic field: 1 – low; 2 – high". The results of this stage of the analysis indicate that with the weakening of the intensity of the geomagnetic field the subjects showed a significant decrease in BMI, heart rate and DLBM accompanied by an increase in oxygen demand at rest and an increase in LBM. This complex of responses and manifestations was accompanied by the significant changes in steroidogenesis, expressed in a decrease in blood concentrations of progesterone, cortisol and dihydrotestosterone, which, in general, indicates an increase in the proportion of lipids in the processes of energy expenditure due to increased use of endogenous fat reserves, confirmed by a decrease in the values of the respiratory coefficient – i.e., the beginning of the implementation of a known pattern of adaptive reactions to extreme environmental factors’ exposure.

The results of studying the effect of physical activity in conditions of 14-day isolation of mixed groups examined with (PHE+) and without preventive physical exercises (PHE-) are presented in Tables 2 and 3. All the indicators determined during the isolation period were within the physiological norm, except elevated concentrations of aldosterone in the blood of the test-subjects in both groups. It could be caused by an adherence to a low salt diet or by low relative humidity in hermetic objects (coefficient of linear correlation of aldosterone with humidity: r=-0,666; p=0,018 n=12) and, especially, by moderate hypercapnia (CO_2 air concentration ~10-15 times higher comparing to the normal terrestrial conditions), which induce the complex of reactions directed to compensate of forced (environmental) respiratory acidosis by metabolic alkalosis through accumulation of bicarbonate ions in blood, formation of reserve of anions and urinal elimination of excess of H+ ions with participation of steroid hormones influencing water-electrolyte homeostasis, especially, of aldosterone [1], [2], [8], [23] (coefficient of linear correlation of aldosterone % with CO_2: r=-0,666; p=0,018 n=12), which is accompanied by the hypohydration and hypovolemia (coefficient of linear correlation of aldosterone % with TBW% and ECW%: r=-0,733; p=0,007; r=-0,705; p=0,011; n=12, correspondingly).

Concerning the effect of physical activity in short-term isolation the average group values (Table 2) revealed significantly higher values of CF%, LBM%, ICS% and DLBM% against the background in the PHE+group compared to the subjects of the PHE-group accompanied by the decrease in their (PHE+) relative blood concentrations of aldosterone and total testosterone, which was obviously directly caused by the use of preventive physical loads, since earlier studies by C.E. Wade and co-workers (1993) showed a decrease in testosterone concentration during intensive physical training in ANOH conditions [9]. However, in this series of studies the significant differences between the groups of the BCM%/ICS% ratio were obtained of the lower extremities (PHE-: 97,7±0,6 vs. PHE+: 94,9±0,5; p<0,05), the proportion of BCM and dry mass of the lower extremities in the total amount of BCM and DLBM – (PHE-: 37,2±1,9% vs. PHE+: 23,5±0,7%; p<0,05; PHE-: 39,2±2,0% vs. PHE+: 29,9±0,8%; p<0,05; correspondingly) and direct reliable correlations with relative values (% to background) of total testosterone and aldosterone concentrations were observed between the proportions of BCM and the dry mass of the lower extremities in the total number of BCM and DLBM (% to background) of total testosterone and aldosterone concentrations (the share in BCM – testosterone % r=0,747; p<0,05; the share in BCM – aldosterone r=0,742; p<0,05; the share in DLBM – testosterone % r=0,645; p<0,05; the share in DLBM – aldosterone r=0,801; p<0,05). In addition, significant negative correlations of the use of the physical exercises with BCM%/ICS% were noted, and between the fractions of BCM and the dry lean mass of the lower extremities in the total amount of BCM and DLBM (r=-0,773; r=-0,906 r=-0,802; p <0,003; correspondingly).

The results of multiple correlation analysis of the entire data array obtained in isolation (12 cases x 9 variables), in which the dependent variable was the "rank level of physical exercise: 1 – no; 2 – yes" are presented in Table 3. It is shown that the use of physical activity in isolation conditions caused an increase in the ICS and the share of EXCF in the volume of total body water, accompanied by an increase in the concentration of aldosterone in the blood. At the same time, the absence of physical exercises in isolation significantly and positively correlated with an increase in body cell mass and an increase in the level of total testosterone concentration in the blood, and these results obtained in isolation together with the above presented results definitely indicate an adverse effect of physical training and the involvement of mineralocorticoids and androgens in the regulation of the component composition of the lower extremities – the most important component of the musculoskeletal system of a modern human – the descendant of “Homo erectus” but such studies certainly require continuation with a large number of observations.

Table 1 - Body composition, physiological and hormonal parameters of test-subjects in dry immersion

DOI: https://doi.org/10.23670/IRJ.2022.126.35.1

Parameter, units of measurement	Background	Dry immersion
Body mass, kg	72,7±3,8	70,8±2,6
Body mass, %	100±0	97,4±0,3*
Body mass index, kg/m^2	23,3±1,1	22,4±0,7
Body mass index, %	100±0	96,0±0,4*
Body surface area, m^2	1,89±0,05	1,87±0,04
Body temperature, °C	36,3±0,1	36,1±0,1
APs, mm Hg	116±2	110±1*
APd, mm Hg	72±2	70±2
Heart rate, beats/minute	67±3	61±2
Cardiac output, L/minute	4,8±0,2	4,2±0,2*
Specific REE, MJ/m^2/day	3,8±0,01	3,8±0,01
Water intake, ml/day	2538±216	2173±181*
Diuresis, ml/day	2027±213	1843±219
Partial water balance, ml/day	511±128	330±99
Protein, g/L	71,1±0,8	71,7±0,6
Albumin, g/L	43,9±0,5	44,5±0,4
Globulins, g/L	27,3±0,9	27,2±0,7
Progesterone, nmol/L	0,7±0,1	1,1±0,1
Progesterone, %	100±0	166±19*
Cortisol, nmol/L	469±26	536±26
Cortisol, %	100±0	116±6*
Free cortisol, nmol/L	90,1±13,2	120,9±4,4
Testosterone, nmol/L	20,6±0,7	23,5±0,9
Testosterone, %	100±0	114±4*
Free testosterone, pmol/L	106±23	120±21
Aldosterone, pmol/L	450±14	490±10*
Aldosterone, %	100±0	114±4*
Estradiol, pmol/L	176±11	191±27

*Note: * - significant difference with background (p <0,05); APs – arterial pressure systolic; APd – arterial pressure diastolic; REE – rest energy expenditure; VO2 – oxygen demand; n=10; Mean±S.E.M*

Table 2 - Body composition, physiological and hormonal parameters of test-subjects in different series of research

DOI: https://doi.org/10.23670/IRJ.2022.126.35.2

Parameter, units of measurement	N=8		Isolation (n=12)	
	Placebo	HGMF	PHE-	PHE+
Body mass, kg	78,7±3,6	78,4±3,7	68,2±7,2	68,1±5,0
Body mass index, kg/m^2	24,2±1,0	24,1±1,1	23,9±1,9	22,4±1,1
APs, mm Hg	117±4	117±2	–	–
APd, mm Hg	71±2	71±2	–	–
Heart rate, beats/minute	58±3	57±3	–	–
Cardiac output, L/minute	4,4±0,3	4,3±0,2	–	–
Extracellular fluid, L	20,4±0,9	20,8±0,9	17,9±1,7	18,2±1,4
Extracellular fluid, % to background	100±2	102±3	100±1	103±1
Cellular fluid, L	25,9±1,1	26,2±1,0	24,9±2,1	22,6±1,6
Cellular fluid, % to background	102±2	104±2	98±1	101±1*
Lean body mass, kg	63,3±2,6	64,2±2,6	58,4±5,2	55,8±4,0
Lean body mass, % to background	101±1	103±2	99±1	102±1*
Body cell mass, kg	38,9±1,5	39,4±1,3	30,3±2,2	35,8±1,7
Body cell mass, % to background	106±4	108±4	100±1	101±1
Intracellular substance, kg	24,4±1,3	24,9±1,5	28,1±3,1	20,0±2,3
Intracellular substance, % to background	96±5	97±4	97±1	104±1*
Dry lean body mass, kg	17,0±0,7	17,2±0,7	15,7±1,4	15,0±1,1
Dry lean body mass, % to background	101±1	103±2	99±1	102±1*
REE, $MJ/m^2/day$	4,0±0,1	4,0±0,1	4,2±0,3	4,0±0,2
Resting VO_2, L/minute	0,26±0,02	0,27±0,01	–	–
Respiratory coefficient	0,92±0,05	0,89±0,04	–	–
Cortisol, nmol/L	149±15	167±52	369±51	467±29
Cortisol in saliva, nmol/L	70,1±5,5	93,9±20,8	–	–
Aldosterone, pmol/L	141±36	187±42	**968±159**	**801±94**
Aldosterone, % to background	103±30	129±38	138±17	89±2*
Testosterone, nmol/L	–	–	12,1±3,6	9,1±3,4
Testosterone, % to background	–	–	116,8±8,0	87,3±5,5*
Free testosterone, pmol/L	226±43	248±37	–	–
Dihydrotestosterone, nmol/L	1,7±0,1	1,6±0,2	–	–

Estradiol, pmol/L	296±55	309±49	–	–
Progesterone, nmol/L	0,48±0,23	0,30±0,09	–	–

*Note: HGMF – hypogeomagnetic field; PHE – physical exercises in isolation (range); * - significant difference between PHE- and PHE+ (p <0,05); APs – arterial pressure systolic; APd – arterial pressure diastolic; REE – rest energy expenditure; VO2 – oxygen demand; Numbers in bold – means are higher than physiological norm; Mean±S.E.M.*

Table 3 - Results of multiple correlation analyses

DOI: https://doi.org/10.23670/IRJ.2022.126.35.3

Independent variables	Dependent variables (BETA±standard error)		
	BMI%*	PHE-Isolation	GMF*
Age	-0,28	–	–
Body mass index %	–		0,27
Heart rate		–	0,14
Arterial pressure diastolic	-0,77	–	–
Cardiac output	-0,16	–	
Resting VO_2	–	–	-1,41
Respiratory coefficient %	–	–	2,85
Extracellular/cellular fluids	–	0,52±0,05	–
Lean body mass %	–	–	-8,98
Body cell mass %	–	-0,13±0,05	
Intracellular substance %	–	0,67±0,04	
Dry lean body mass %	–		8,00
Progesterone %	0,74	–	1,50
Cortisol %	-0,89		0,39
Free cortisol %	0,09	–	–
Aldosterone %	-1,28	0,22±0,08	
Testosterone %	0,46	-0,23±0,04	–
Free testosterone %	-0,24	–	
Testosterone free/total %	-0,64	–	–
Dihydrotestosterone %	–	–	1,85
Cortisol /testosterone	1,76	–	–
Estradiol/testosterone %	0,71	–	–
Final results of multiple correlation analyses			
Significance of F-test, p	0,004	<0,0001	0,002
Coefficient of multiple correlation (R)	>0,999	0,998	>0,999
Coefficient of multiple determination (R^2)	>0,999	0,996	>0,999
Adjusted R^2	>0,999	0,990	>0,999
Standard error of estimate	0,006	0,052	0,002

*Note: BETA – standardized regression coefficients (p <0,05), empty cells – variables not included in the final equation of multiple regression; % – percentage of changes relative to background; BMI – body mass index in dry immersion; PHE – physical exercise (range); GMF – geomagnetic field (range); * – standard error of BETA <0,04*

Conclusion

The results of studies in the 21-day DI indicate the relationship of steroid hormones with hemodynamic parameters and body composition, which have a positive orientation in older people and contribute to their better adaptation to a complex of influencing factors.

It is shown that the weakening of the intensity of the geomagnetic field initiates an increase in lean body mass and oxygen consumption at rest, accompanied by a decrease in steroid secretion and respiratory coefficient – the development of characteristic adaptive reactions to the effects of extreme habitat.

The results of complex studies in conditions of short–term isolation revealed the adverse effect of intensive physical training and the involvement of mineralocorticoids and androgens in the regulation of the component composition of the lower extremities - the most important component of the musculoskeletal system of a modern human – the descendant of “Homo erectus”.

Финансирование

The work was supported by the Program of Fundamental Research of the SSC RF-IMBP RAS for 2013-2020 and the topic of RAS No. 65.1.

Funding

Работа была поддержана Программой фундаментальных исследований ГНЦ РФ-ИМБП РАН на 2013-2020 годы и темой РАН № 65.1.

Благодарности

Авторы выражают глубокую признательность и благодарность организаторам модельных исследований и всем их участникам.

Acknowledgement

The authors express their deep appreciation and gratitude to the organizers of the simulating studies and all their participants.

Конфликт интересов

Не указан.

Conflict of Interest

None declared.

Рецензия

Все статьи проходят рецензирование. Но рецензент или автор статьи предпочли не публиковать рецензию к этой статье в открытом доступе. Рецензия может быть предоставлена компетентным органам по запросу.

Review

All articles are peer-reviewed. But the reviewer or the author of the article chose not to publish a review of this article in the public domain. The review can be provided to the competent authorities upon request.

Список литературы / References

1. Nicogossian A.E. Space physiology and medicine. From evidence to practice / Ed. by A.E. Nicogossian, R.S. Williams, C.L. Huntoon et al. — New York : Springer, 2016. — Vol. XXIII. — 509 p.— DOI: 10.1007/978-1-4939-6652-3.
2. Smith C.M. Human adaptation to spaceflight: the role of food and nutrition / C.M. Smith, S.R. Zwart, G.L. Dauglaset al. — Second edition. — Houston, TX : NASA Lyndon B. Johnson Space Center, 2021. — 255 p.
3. Stowe R.P. Adrenocortical and immune responses following short- and long-duration spaceflight / R.P. Stowe, C.F. Sams, D.L. Pierson // Aviat. Space Environ. Med. — 2011. — Vol. 82. — № 6. — P. 627-634.
4. Strollo F. Changes in human adrenal and gonadal function onboard Spacelab / F. Strollo, G. Strollo, M. More et al. // J. Gravit. Physiol. — 1997. — Vol. 4. — № 2. — P. 103-104.
5. Smith S.M. Long-duration space flight and bed rest effects on testosterone and other steroids / S.M. Smith, M. Heer, Z. Wang et al. // J. Clin. Endocrinol. Metab. — 2012. — Vol. 97. — № 1. — P. 270–278.
6. Jain V. Potential venous thromboembolism risk in female astronauts / V. Jain, R. Ploutz-Snyder, M. Young et al. // Aerosp. Med. Hum. Perform. — 2020. — Vol. 91. — № 5. — P. 432-439. — DOI: 10.3357/AMHP.5458.2020.
7. Zwart S.R. Albumin, oral contraceptives, and venous thromboembolism risk in astronauts / S.R. Zwart, S.M. Auñón-Chancellor, M, Heer et al. // J. Appl. Physiol. — 2022. — Vol. 32. — № 5. — P. 1232-1239. — DOI: 10.1152/japplphysiol.00024.2022.
8. Maillet A. Effects of 28-day isolation (ESA-ISEMSI'90) on blood pressure and blood volume regulating hormones / A. Maillet, H.C. Gunga, G. Gauquelin et al. // Aviat. Space Environ. Med. — 1993. — Vol. 64. — № 4. — P. 287-294.
9. Wade C.E. Intensive exercise training suppresses testosterone during bed rest / C.E. Wade, K.I. Stanford, T.P. Stein et al. // J. Appl. Physiol. — 2005. — Vol. 99. — № 1. — P. 59-63. — DOI: 10.1152/japplphysiol.00332.2004.
10. Abeln V. Chronic, acute and protocol-dependent effects of exercise on psycho-physiological health during long-term isolation and confinement / V. Abeln, E. Fomina, J. Popova // BMC Neurosci. — 2022. — Vol. 23(1). — P. 41. — DOI: 10.1186/s12868-022-00723-x. — URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9244384/ (accessed: 14.06.2022).
11. Maillet A. Effects of a 60-day confinement on the blood pressure, hormonal responses and body fluids of a mixed crew / A. Maillet, H.C. Gunga, S. Normand et al. // J. Gravit. Physiol. — 1998. — Vol. 5. — № 2. — P. 55-64.
12. Coupé M. Body fluid changes, cardiovascular deconditioning and metabolic impairment are reversed 24 hours after a 5-day dry immersion / M. Coupé, E. Tomilovskaya, F. Larcher et al. // Open Journal of Nephrology — 2013. — № 3. — P. 13-24.
13. Tomilovskaya E. Dry immersion as a ground-based model of microgravity physiological effects / E. Tomilovskaya, T. Shigueva, T. D. Sayenko et al. // Front. Physiol. — 2019. — № 10. — P. 284. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6446883/ (accessed: 14.06.2022).
14. Nichiporuk I.A. Dynamics of water-electrolyte homeostasis. Neurohormonal regulation of metabolism / I.A. Nichiporuk, B.V. Afonin, V.Yu. Semenov et al. // Annual antiorthostatic hypokinesia (ANOH) – a physiological model of

interplanetary space flight / Ed. by A.I. Grigoriev, I.B. Kozlovskaya. — M. : Russian Academy of Sciences, 2018. — P. 165-209.

15. Nichiporuk I.A. The state of the male reproductive system in conditions of anti-antiorthostatic hypokinesia / I.A. Nichiporuk, V.V. Evdokimov, A.G. Goncharova et al. // Problems of reproduction. — 1999. — Vol. 5. — № 5. — P. 35-38.

16. Chistokhodova S.A. Dynamics of steroidogenesis and concentration in the blood of the main substrates of energy exchange as links in the strategy of adaptation to a changed environment / S.A. Chistokhodova // Materials of the XVII conference of young scientists, specialists and students dedicated to the 100th anniversary of the birth of academician O.G. Gazenko. — M. : Institute of Biomedical Problems of the Russian Academy of Sciences, 2018. — P. 127-130.

17. Chistokhodova S.A. Features of the dynamics of steroid hormones in men under conditions of 21-day dry immersion and its relationship with the psychophysiological state / S.A. Chistokhodova, O.A. Zhuravleva, I.A. Nichiporuk // Materials of the XIX Conference of young scientists, specialists and students dedicated to the 60th anniversary of the first human flight into space. — Moscow : Institute of Biomedical Problems of the Russian Academy of Sciences, 2021. — P. 81-84.

18. Downs M.E. Exercise and testosterone countermeasures to mitigate metabolic changes during bed rest / M.E. Downs, J.M. Scott, L.L. Ploutz-Snyder et al. // Life Sci. Space Res. — 2020. — Vol. 26. — № 8. — P. 97-104. — DOI: 10.1016/j.lssr.2020.03.008.

19. Zhuravleva T.V. Psychological, neurohormonal and metabolic features of adaptation of the participants of the SIRIUS 18/19 experiment to the conditions of 120-day isolation in a hermetic object / T.V. Zhuravleva, I.A. Nichiporuk, Yu.A. Bubeev et al. // Aerospace and environmental medicine. — 2021. — Vol. 55. — № 2. — P. 48-55.

20. Patel Z.S. Red risks for a journey to the red planet: The highest priority human health risks for a mission to Mars / Z.S. Patel, T.J. Brunstetter, W.J. Tarver // NPJ. Microgravity. — 2020. — № 6(1). — P. 33. — URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7645687/pdf/41526_2020_Article_124.pdf (accessed: 15.02.2022).

21. Liljestrand G. Vergleichen die Bestimmungen des Minutenvolumens des Herzens beim Menschen mittels der Stichoxydulmethode und durch Blutdruckmessung / G. Liljestrand, E. Zander // Ztschr. Ges. exper. med. — 1928. — Vol. 59. — P. 105–122.

22. Nikolaev D. V. Bioimpedance analysis of human body composition / D.V. Nikolaev, A.V. Smirnov, I.G. Bobrinskayaet al. — M. : Nauka, 2009. — 390 p.

23. Nichiporuk I. The impact of microclimate parameters of long-term space flights and commensurable simulating confinements on the human psychophysiological state and body composition / I. Nichiporuk, O. Zhuravleva, S. Chistokhodova et al. // Proceedings of the Global Space Exploration Conference (GLEX 2021). — St.-Petersburg, 2021. — 6 p.

24. Rebrova O.Y. Statistical analysis of medical data. Application of the STATISTICA application software package / O.Y. Rebrova. — M. : Media Sphere Publishing House, 2006. — 305 p.

Список литературы на английском языке / References in English

1. Nicogossian A.E. Space physiology and medicine. From evidence to practice / Ed. by A.E. Nicogossian, R.S. Williams, C.L. Huntoon et al. — New York : Springer, 2016. — Vol. XXIII. — 509 p.— DOI: 10.1007/978-1-4939-6652-3.

2. Smith C.M. Human adaptation to spaceflight: the role of food and nutrition / C.M. Smith, S.R. Zwart, G.L. Dauglaset al. — Second edition. — Houston, TX : NASA Lyndon B. Johnson Space Center, 2021. — 255 p.

3. Stowe R.P. Adrenocortical and immune responses following short- and long-duration spaceflight / R.P. Stowe, C.F. Sams, D.L. Pierson // Aviat. Space Environ. Med. — 2011. — Vol. 82. — № 6. — P. 627-634.

4. Strollo F. Changes in human adrenal and gonadal function onboard Spacelab / F. Strollo, G. Strollo, M. More et al. // J. Gravit. Physiol. — 1997. — Vol. 4. — № 2. — P. 103-104.

5. Smith S.M. Long-duration space flight and bed rest effects on testosterone and other steroids / S.M. Smith, M. Heer, Z. Wang et al. // J. Clin. Endocrinol. Metab. — 2012. — Vol. 97. — № 1. — P. 270–278.

6. Jain V. Potential venous thromboembolism risk in female astronauts / V. Jain, R. Ploutz-Snyder, M. Young et al. // Aerosp. Med. Hum. Perform. — 2020. — Vol. 91. — № 5. — P. 432-439. — DOI: 10.3357/AMHP.5458.2020.

7. Zwart S.R. Albumin, oral contraceptives, and venous thromboembolism risk in astronauts / S.R. Zwart, S.M. Auñón-Chancellor, M, Heer et al. // J. Appl. Physiol. — 2022. — Vol. 32. — № 5. — P. 1232-1239. — DOI: 10.1152/japplphysiol.00024.2022.

8. Maillet A. Effects of 28-day isolation (ESA-ISEMSI'90) on blood pressure and blood volume regulating hormones / A. Maillet, H.C. Gunga, G. Gauquelin et al. // Aviat. Space Environ. Med. — 1993. — Vol. 64. — № 4. — P. 287-294.

9. Wade C.E. Intensive exercise training suppresses testosterone during bed rest / C.E. Wade, K.I. Stanford, T.P. Stein et al. // J. Appl. Physiol. — 2005. — Vol. 99. — № 1. — P. 59-63. — DOI: 10.1152/japplphysiol.00332.2004.

10. Abeln V. Chronic, acute and protocol-dependent effects of exercise on psycho-physiological health during long-term isolation and confinement / V. Abeln, E. Fomina, J. Popova // BMC Neurosci. — 2022. — Vol. 23(1). — P. 41. — DOI: 10.1186/s12868-022-00723-x. — URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9244384/ (accessed: 14.06.2022).

11. Maillet A. Effects of a 60-day confinement on the blood pressure, hormonal responses and body fluids of a mixed crew / A. Maillet, H.C. Gunga, S. Normand et al. // J. Gravit. Physiol. — 1998. — Vol. 5. — № 2. — P. 55-64.

12. Coupé M. Body fluid changes, cardiovascular deconditioning and metabolic impairment are reversed 24 hours after a 5-day dry immersion / M. Coupé, E. Tomilovskaya, F. Larcher et al. // Open Journal of Nephrology — 2013. — № 3. — P. 13-24.

13. Tomilovskaya E. Dry immersion as a ground-based model of microgravity physiological effects / E. Tomilovskaya, T. Shigueva, T. D. Sayenko et al. // Front. Physiol. — 2019. — № 10. — P. 284. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6446883/ (accessed: 14.06.2022).

14. Nichiporuk I.A. Dynamics of water-electrolyte homeostasis. Neurohormonal regulation of metabolism / I.A. Nichiporuk, B.V. Afonin, V.Yu. Semenov et al. // Annual antiorthostatic hypokinesia (ANOH) – a physiological model of

interplanetary space flight / Ed. by A.I. Grigoriev, I.B. Kozlovskaya. — M. : Russian Academy of Sciences, 2018. — P. 165-209.

15. Nichiporuk I.A. The state of the male reproductive system in conditions of anti-antiorthostatic hypokinesia / I.A. Nichiporuk, V.V. Evdokimov, A.G. Goncharova et al. // Problems of reproduction. — 1999. — Vol. 5. — № 5. — P. 35-38.

16. Chistokhodova S.A. Dynamics of steroidogenesis and concentration in the blood of the main substrates of energy exchange as links in the strategy of adaptation to a changed environment / S.A. Chistokhodova // Materials of the XVII conference of young scientists, specialists and students dedicated to the 100th anniversary of the birth of academician O.G. Gazenko. — M. : Institute of Biomedical Problems of the Russian Academy of Sciences, 2018. — P. 127-130.

17. Chistokhodova S.A. Features of the dynamics of steroid hormones in men under conditions of 21-day dry immersion and its relationship with the psychophysiological state / S.A. Chistokhodova, O.A. Zhuravleva, I.A. Nichiporuk // Materials of the XIX Conference of young scientists, specialists and students dedicated to the 60th anniversary of the first human flight into space. — Moscow : Institute of Biomedical Problems of the Russian Academy of Sciences, 2021. — P. 81-84.

18. Downs M.E. Exercise and testosterone countermeasures to mitigate metabolic changes during bed rest / M.E. Downs, J.M. Scott, L.L. Ploutz-Snyder et al. // Life Sci. Space Res. — 2020. — Vol. 26. — № 8. — P. 97-104. — DOI: 10.1016/j.lssr.2020.03.008.

19. Zhuravleva T.V. Psychological, neurohormonal and metabolic features of adaptation of the participants of the SIRIUS 18/19 experiment to the conditions of 120-day isolation in a hermetic object / T.V. Zhuravleva, I.A. Nichiporuk, Yu.A. Bubeev et al. // Aerospace and environmental medicine. — 2021. — Vol. 55. — № 2. — P. 48-55.

20. Patel Z.S. Red risks for a journey to the red planet: The highest priority human health risks for a mission to Mars / Z.S. Patel, T.J. Brunstetter, W.J. Tarver // NPJ. Microgravity. — 2020. — № 6(1). — P. 33. — URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7645687/pdf/41526_2020_Article_124.pdf (accessed: 15.02.2022).

21. Liljestrand G. Vergleichen die Bestimmungen des Minutenvolumens des Herzens beim Menschen mittels der Stichoxydulmethode und durch Blutdruckmessung [Compare the determinations of the minute volume of the heart in humans by means of the puncture oxydule method and by measuring blood pressure] / G. Liljestrand, E. Zander // Ztschr. Ges. exper. med. – 1928. – Vol. 59. – P. 105–122. [in German]

22. Nikolaev D. V. Bioimpedance analysis of human body composition / D.V. Nikolaev, A.V. Smirnov, I.G. Bobrinskayaet al. — M. : Nauka, 2009. — 390 p.

23. Nichiporuk I. The impact of microclimate parameters of long-term space flights and commensurable simulating confinements on the human psychophysiological state and body composition / I. Nichiporuk, O. Zhuravleva, S. Chistokhodova et al. // Proceedings of the Global Space Exploration Conference (GLEX 2021). — St.-Petersburg, 2021. — 6 p.

24. Rebrova O.Y. Statistical analysis of medical data. Application of the STATISTICA application software package / O.Y. Rebrova. — M. : Media Sphere Publishing House, 2006. — 305 p.