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NASA TECHNICAL MEMORANDUM NASA TM-76014

RESULTS OF MEDICAL STUDIES DURING LONG-TERM MANNED FLIGHTS ON THE ORBITAL SALYUT-6 AND SOYUZ COMPLEX

A.D. Yegorov, Compiler

Translation of "Rezultaty meditsinskikh issledovaniy vo vremya dlitel'nykh pilotiruyemykh polyetov na orbital'nom komplekse "Salyut-6"--"Soyuz", Academy of Sciences USSR, Ministry of Public Health, Institute of Medical and Biological Problems, Moscow, 1979

(NASA-TM-76014) RESULTS OF MEDICAL STUDIES DURING LONG-TERM MANNED FLIGHTS ON THE ORBITAL SALYUT-6 AND SOYUZ COMPLEX (National Aeronautics and Space Administration) 245 p HC A11/MF A01 CSCL 06P G3/52

N80-15797

Unclas 46657

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 NOVEMBER 1979

Preface

In the USSR in 1977-1978, manned flights were made on the orbital Salyut-6 and Soyuz complex; these flights lasted 96 days (first main expedition: Commander CC-I Yu. V. Romanenko, flight engineer FE-I G.M. Grechko and 140 days (second main expedition: Commander CC-II V.V. Kovalënok, flight engineer FE-II A.S. Ivanchenkov). The main landmarks for each of these flights of unprecedented duration were the following: egress and work by the crews outside the orbital complex; joint work during each flight with two visiting crews, and also the first main expedition from one to another, with three transportation cargo spacecraft; fulfilling numerous scientific, scientific-technical, medical-biological experiments and observations.

During flight, the first main crew (MC-I) carried out joint work with two visiting expeditions (VC-I and VC-II): the first crew consisted of V.A. Dzhanbekov and O.G. Makarov, the second comprised A.A. Gubarev and citizen of the Czechoslovakian SSR, V. Remek. The second main crew (MC-II) worked jointly with two visiting international expeditions comprised of: P.I. Klimuk and M. Germashevskiy (Polish People's Republic), V.F. Bykovskiy and Z. Yen (German Democratic Republic).

The basic medical tasks consisted of maintaining a good state of health and adequate work capability of the crews in flight, in the conduct of medical examinations, control of a complex of prophylactic measures in order to prevent the unfavorable effect of flight factors on the organism of Man and preparation of the basic crews for the effect of Earth's force of gravity.

Medical examinations during the 96 and 140-day flights included the following:

--electrocardiograph examination (12 ordinarily used points of contact);

--the study of hemodynamics at rest and when carrying out functional tests with measured physical load and when applying negative pressure on the lower part of the body;

--a study of the central and regional hemodynamics by a rheographic method;

--a study of pressure in the jugular vein (phlebographic method) and venous pressure in the blood vessels of the crus (plethysmographic method);

--study of the phase structure of the cardiac cycle at rest and during functional load;

--dynamic electrocardiograph study;

--hematologic study (taking blood from the finger) and biochemical studi of the urine (using indicator strips);

--the study of water salt exchange and sodium of the excretory function of the salivary glands;

--study of the dynamics of body mass and the volume of the crura;

--microbiological studies.

In the postflight period, the studies were conducted with the following approach:

--an evaluation of the general state of the crew when examined by clinical specialists;

--study of the state of the cardiorespiratory system at rest and during functional tests;

--study of the nerve and muscle apparatus and the motor sphere;

--a broad spectrum of laboratory, biochemical, hematologic, immunologic and microbiologic studies;

--study of the salt water exchange and functioning of the kidneys.

The clinical and physiological examinations made it possible to evaluate the state of practically all systems of the organism, to make more precise the phenomonology developed during and after flight of changes of the basic functions of the organism and to provide an effective tactic for the regeneration measures in the readaptation period. In this respect, the basic results of the investigations made are presented in the following sections:

1. Characteristics of conditions of flight in the orbital complex and the general condition of the cosmonauts.

2. Studies of the cardiovascular system.

3. Study of the motor sphere and vestibular analyzer.

4. Biochemical, hematologic, immunologic and biochemical studies.

5. Recovery measures in the readaptation period.

List of Abbreviations

MC-I and MC-II -- first and second main crews;

CC -- crew commander;

FE -- flight engineer;

VC -- visiting crew;

BE -- bicycle ergometer;

CPT -- complex physical trainer;

PR -- pulse rate;

FCC -- frequency of cardiac contraction;

LBNP -- negative pressure applied to the lower part of the body.

Translator's note: The author's list of abbreviations seems inadequate. To assist the reader, I have tried to list all of the abbreviations by section. They appear in the approximate order in which they occur in the text.

Part II:

FAP -- femoral artery pulse

KCG -- kinetic cardiogram

TO -- tacho-oscillogram

PM -- pressure markers

IPB -- index of pulse blood filling

AC -- asynchronous contraction

IC -- isovolumetric contraction

PE -- period of ejection

PD -- protodiastoles

RF -- rapid filling

SF -- slow filling

IR -- isometric relaxation

D -- diastole

SA -- systoles of the auricle

REG -- rheoencephalogram

RG -- rheogram

PG -- pneumogram

SCG -- seismocardiogram

PrD -- protodiastole interval

VP -- voltage period

St -- total systole

MS -- mechanical systole

VIM -- voltage index of the myocardium

ISI -- intrasystolic index

Vi -- intraventricular pressure

SV -- stroke volume

RPPWa -- rate of propagation of the pulse wave along the aorta

PP -- pulse pressure

S -- systole

T -- full cardiac cycle

MO -- minute volume

SPR -- specific peripheral resistance

MVC -- minute volume of circulation

DcI -- dicrotic index

VAP -- venous arterial pulsogram

PLC -- plethysmogram of the crus

LV -- left ventricle

PB -- pulse blood

MB -- minute blood

AP -- arterial pressure

ESV -- end systolic volume

MPL -- measured physical load

EDV -- end diastolic volume

SE -- stroke ejection

DLA -- diameter of the left auricle

TMD -- thickness of the myocardium

SI -- stress index

Part III:

BP -- background period

EMG -- electromyogram

EMEM -- electromechanical effectiveness method

OCGB -- overall center of gravity of the body

Part IV:

NEFA -- non-intensified fatty acids

LDH -- lactate dehydrogenase

MDH -- malate dehydrogenase

ICDH -- isocitrate dehydrogenase

OBDH -- oxybutyrate dehydrogenase

CPK -- creatin phosphokinase

ALT -- alanine aminotransferase

AlP -- alkali phosphatase

PG -- prostaglandin

TTH -- thyreotropic hormone

STH -- somatropic hormone

F -- cortisol

CET -- coefficient of effective thyroxin

AMP -- adenosine monophosphate

GMP -- guanesinemonophosphoric acid

c -- cyclic

KS -- ketosteroid

SAS -- sympato-adrenal system

E -- epinephrine

NE -- norepinephrine

DA -- dofamine

DOPA -- dihydroxyphenylalanine

MN -- metanephrine

NMN -- normetanephrine

VAA -- vanillyl-mandelic acid

HVA -- homovanillic

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RESULTS OF MEDICAL STUDIES DURING LONG-TERM MANNED FLIGHTS ON THE ORBITAL SALYUT-6 AND SOYUZ COMPLEX

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PART I

CHARACTERISTICS OF FLIGHT CONDITIONS IN THE ORBITAL COMPLEX AND THE GENERAL STATE OF THE COSMONAUTS

1.1. Environment of the Living Area and Sanitary and Hygienic Measures in the Salyut-6 Orbital Station /7*

During the stay of the cosmonauts in the Salyut-6 orbital station, the parameters of barometric pressure were constantly controlled as well as the gaseous composition of the air medium and the microclimate. Periodically a control test was made of the chemical composition of the air for content of harmful admixtures and also the sanitary state of the life medium. Samples were sent to Earth with visiting expeditions for chemical and bacteriologic analysis to be carried out in detailed laboratory studies.

The sanitation and living provisions for the Salyut-6 orbital station were accomplished by taking measures directed at maintaining the "purity" in the rooms and also for satisfying conditions of personal hygiene of the cosmonauts. Here, a periodic cleaning of the rooms of the station was carried out using a vacuum cleaner and with obligatory processing of the internal surfaces using a cloth moistened with a disinfecting substance. The products of the life activity of the cosmonauts (feces, urine) and also accumulated trash (food leftovers, packing from instruments, food products, personal hygiene equipment, etc.) were collected into special hermetically sealed containers. The latter, periodically, as they accumulated, were removed from the spacecraft through a special lock chamber. After some time these containers entered the dense layers of Earth's atmosphere where they burned up completely.

During the stay of the second main crew, the volume of work directed at providing "purity" in the rooms of the station were increased. Cleaning the rooms was done more frequently, on specially designated "sanitation days," when a large part of the internal surfaces of the station were subjected to this disinfecting treatment.

Toothbrushes, toothpaste, masticatory elastics for treatment and prophylactic effect, a cloth made of antibacterial material, /8
moistened with sanitizing lozenges were all used for oral hygiene. To clean their skin the cosmonauts used napkins and

*Numbers in the margin indicate pagination in the foreign text.

towels made of antibacterial cloth, dry and moistened with purifying lozenges. These articles were used by the cosmonauts for moist wiping of the entire body after carrying out physical exercises.

For the first time on an orbital station, on the Salyut-6 an experimental system for water procedures was tested made in the form of a shower cabinet, a heating system and a water supply and also collection and subsequent storage of the water so used. The cosmonauts of the first main expedition used two shower procedures, and the second crew three procedures. During the water procedures, the main crews used cloths which had good cleaning and disinfecting properties.

The gaseous medium in the living quarters of the orbital complex during the flights of the first and second main crews were similar to the parameters of Earth's atmosphere. The limits of variation of the main indices of the medium in the living sections were:

-- total pressure 733--847 mm mercury column;

-- partial pressure of oxygen 158--229 mm mercury column;

-- partial pressure of carbon dioxide 1.23--7.44 mm mercury column;

-- partial pressure of water vapor 7.0--16.4 mm mercury column;

-- air temperature 19.0--24.5° C.

The sanitary and epidemiologic state of the living environment on the Salyut-6 orbital station during the stay of cosmonauts in it can be characterized as satisfactory. In the first place, this circumstance involves thorough cleaning by the cosmonauts according to the planned procedure of the rooms of the station using the disinfecting equipment.

It is just this circumstance which was the reason that the level of total bacterial contamination of the air in the rooms of the orbital complex during the stay of V.V. Kovalënok and A.S. Ivanchenkov was maintained primarily within limits under 400 microbe cells per 1 m^3 of air and the content of bacteria on the surface objects located in different areas of the station amounted to 250±100 microbe cells for 100 cm^2 of surface. /9

The microflora of the air and surfaces of the orbital station was primarily nonpathogenic types of bacteria.

The main section of microorganisms were staphylococci, bacteria, gram-positive spore bacilli.

The fungus of the Aspergillus genus was found in single locations.

The saprophytic character of representatives of microflora also attests to the fact that as a rule, the cultures of microorganisms studied are sensitive to most (17 out of 19) antibiotics.

In the stay in the orbital complex the cosmonauts used a broad assortment of equipment for personal hygiene which made it possible to maintain the functional state of the skin and external mucous membranes within limits inherent for a healthy person.

One can also consider that the experimental system of taking showers used for the first time in the orbital Salyut-6 station was of definite value. The cosmonauts noted good hygienic effects after taking a shower.

When using the shower procedure in weightlessness conditions the water, as a rule, tends to accumulate on the walls of the shower cabin, on the skin of the cosmonauts in the form of a layer which is difficult to remove. This circumstance caused certain inconveniences in using the experimental system for taking showers.

1.2. The Radiation Circumstances and Dosimeter Control /9a

When flying the station on pilot, the following parameters for the radiation condition were controlled: the characteristics of solar activity--the area and configuration of groups of spots, radio waves at fixed frequencies, X-ray radiation of the Sun, etc., density of the radiation flux close to Earth and in the upper atmosphere of Earth, the dosimetric characteristics on the complex, the state of the magnetic field of Earth.

As a whole, there was no worsening of the radiation condition during flight of the complex. During the flight, 6 solar flares were recorded accompanied by fluxes of protons in the environs of Earth. In their characteristics, these events were of average intensity, and did not pose a radiation danger for the crew. The strongest flare was noted on 9/23/78, the density of the flux of protons as a maximum amounted to $2.2 \cdot 10^3/cm^2 \cdot s \cdot ster$, the flux for the entire flare is evaluated at $2 \cdot 10^8/cm^2$. This flare produced in a short time an increase in the power of the dose on the station.

Dosimetric control on the orbital complex was accomplished by using two radiometers on the Salyut-6 station (in the working section) and one radiometer on the Soyuz transport spacecraft.

Also in the set of instruments there was included a transfer dosimeter (PPD [perenosnoy dozimetr, transfer dosimeter ZTD]), which made it possible to measure doses and power doses directly practically in any area in the complex. An individual passive means of control was the thermal luminescence, small dimension assemblies (ID [individualnyy dozimetr, individual dosimeter, ID]) which recorded the contaminating component of space radiation (Table 6). Processing and taking a reading of the ID assemblies was done after completion of flight. Table 1.1 shows certain characteristics of the equipment for dosimeter control and Table 1.2, the level of irradiation of the crew. /10

The comparison of power of the doses of irradiation in all crews indicates that the radiation circumstance over a period of about a year /11

TABLE 1.1. CERTAIN CHARACTERISTICS OF THE EQUIPMENT FOR DOSIMETER CONTROL /10

Instrument	Range of power of the doses, rad/hr	Range of rads	Precision %	Dimensions mm^2	Wt kg	Type of information
Radiometer	0.00004-I0	0,0I25-400	20	272xI24xI00	2,3	TM-signal
PTD	0,00003-I00	0,0I-I000	20	I28x68x23	0,35	Reading according to the instrument
ID	0,0003-5·I0³	0,05-5·I0³	20	65x47xI3	0,050	Thermoluminescence

TABLE 1.2. LEVEL OF IRRADIATION OF THE CREWS OF THE COMPLEX

Crew	Duration of work, days	Dose, mbar		Power of the dose, mbar/24 hours
		R-15	ID-3	
MC-I	96	2I00	3200	22 ÷ 33
VC-I-I	6	I50	I70	25 - 28
VC-I-II	8	I90	250	24 - 3I
MC-II	I40	2900	5300	20 ÷ 37
VC-II-I	8	I80	320	23 ÷ 40
VC-II-II	8	I90	380	24 ÷ 47

Notation: MC-I and MC-II are the first and second main crews; VC--is the visiting crew.

remained practically unchanged. This applies to solar flares; for the /11
entire period of operating the station with a manned procedure, only one flare on 9/23/78 resulted in a slight increase in the dosage on board the station (up to 100 mrad) which is explained by the average power of the flares and the screening effect of the geomagnetic field.

The levels of irradiation (for the 140-day flight) had a maximum value of 5.8 bar, which, nevertheless, is significantly smaller than the regulated allowable values.

1.3. Feeding the Crew During Flight

The food unit on the Salyut-6 orbital station included the following components: the food ration; containers for placing and storing products; a table for eating; electric heaters for food; equipment for eating (can openers, , spoons, forks); devices for fixing the products and means of taking the food at the table; a system for regenerating water from the condensates with a device for measuring hot water and injecting it into packets with dehydrated food; equipment for making up dehydrated juices with cold water from containers and its storage. All of the components of the food link in the 96-day flight of the first and 140-day flight of the second expeditions functioned normally. The food ration facilitated keeping the crews of the first two main expeditions healthy, with good work capability, and satisfied the food status.

In the time which elapsed after flights of the Salyut-4 orbital station crews up to the flights of the orbital Salyut-5 and Salyut-6 stations, the food link was significantly improved. The caloric content of the food ration was increased up to 3150 kcal (on the Salyut-4 it had been approximately 2900 kcal) which involves the expansion of the complex of physical trainers for the cosmonauts and /12 an increase in its energy expenditure.

The makeup of the average daily food ration was the following: proteins--135 g, fats--110 g, carbohydrates--380 g, calcium--0.8 g, phosphorus--1.7 g, magnesium--0.4 g, potassium--3.0 g, sodium--4.5 g and iron--50 mg. Twice a day the crew members satisfied their vitamin requirements with a Undevit multivitamin pill. The variety of products used in the rations has been significantly expanded (more than 60 items instead of the 44 used on the Salyut-4) which has made it possible to make up a varied menu for a six day cycle. The following groups of products are in the food ration: meat--25, first courses--6, milk--5, bread--5, confections--10, fruits, juices--12, hot drinks--3, condiments--2. The assortment of products preheated in the improved electric warmer was increased; they are packed in aluminum tubes, tin cans and film packages (the heater on the Salyut-4 heated only products in aluminum tubes). Due to the setup on board the station, the devices for regeneration of water from the condensate made it possible to include dehydrated snacks in the food ration, drinks reconstituted by applying the required hot water. Also, the assortment of fruit-berry and vegetable juices was considerably expanded; these are reconstituted by adding the required amount of cold water using a special device mounted on the containers with the reserve supply of water. About half (34 items) of the products are eaten hot. Each time food is served it includes one to two hot dishes. The listed improvements have significantly decreased the feeling of boredom with the ration products; this has made it possible to recommend its use over the long term in comparison with the preceding flights.

The requirements for food by the cosmonauts of the first main /13 expedition of the Salyut-6 orbital station which lasted for 96 days was unequal; this was mainly due to the different level of physical load at different stages of the flight. In the first week of flight, during the adaptation to weightlessness, the requirement for food was at a level of 2300 kcal per day. Later on, in different flight periods, the calorie content of the average daily ration varied from 2400 to 3000 kcal.

Considering the desires of the crew, during the flight, in addition to the standard ration on the Soyuz-27 and Progress-1 spacecraft, a fairly broad assortment of different products is supplied (fresh, dehydrated and canned). The cosmonauts expressed great satisfaction with the products supplied. On the 52nd day they reported that they were eating the food with an appetite. However, beginning on the 53rd day, one noted a decrease in appetite which obviously was due to the "boredom" with canned products.

The cosmonauts in the second main expedition of the Salyut-6 station ate a corrected food ration. In this ration, enriched wheat bread was included and at dinner each day a second sublimation dried dish was included and a new assortment of products and dishes was introduced as substitutes for the basic products; also the assortment of fruit and berry juices was expanded. Moreover, the Undevit multivitamin complex was replaced by the Aerovit because the latter was more stable in storage.

In addition to the standard onboard food ration, the crew on the second expedition, like the first, was served fresh products with limited storage time and certain dishes prepared by them from the standard ration--on the Soyuz-30 and Progress-2-4 spacecraft. /14

The cosmonauts of the second main expedition retained a good appetite throughout almost the entire flight. They required on the average a daily ration with the calorie content of about 3000 kcal. During the period when the visiting expedition was on board and when carrying out heavy work, the calorie content required was increased to 3100 kcal.

The food ration was evaluated by the cosmonauts very positively although in taste qualities certain products and dishes received comments.

In the second half of the flight the FE-II had a selectively decreased appetite. It did not finish eating all of the meat dishes, preferring pot cheese, juices and drinks to them. It was in this intermediate period that he underwent a fairly significant loss in weight.

One should note that while the time for completing physical exercises in both cosmonauts is approximately the same, the the intensity of load was considerably greater for the CC-II which undoubtedly played an important role both in maintaining physical status and in retaining good appetite.

1.4. Water Supply for the Crews in Flight

The water supply of the crews of the Salyut-6 complex, was based on reserve supplies of water and also on use of a system for regeneration of water from the condensate of the atmospheric moisture.

As a result of the studies made for the crew of the Soyuz-Salyut complex, a total standard of water requirement was recommended at

2800 ml, including 1700 ml of free drinking water, 800 ml of water for the food ration and 300 ml of water as metabolic. This quantity of liquid makes it possible to retain the water balance in the organism of man affected by the factors of space flight.

The studies made under conditions of automatic and complex testing of water supply systems showed that the method of storage of the water with ionic silver in a dose of 0.2 mg/l provided full retention of the sanitary and hygienic indices of water within the limits of time period envisaged in the flight program. /15

The use of the method developed for storing drinking water with the introduction of an electrolytic solution of ionic silver in a concentration of 0.2 mg/l made it possible to retain high hygienic properties of the water in the water supply system for the orbital complex for the entire flight period of the I and II expeditions on the Salyut-6 station. Supplying the cosmonauts with drinking water from the regeneration system made it possible to provide them with hot drinks, tea, coffee and heated dishes from the food ration.

The SRV-K [Sistema regeneratsii vodoy, korabl, Water regeneration system, spacecraft, WRS-S] system includes in it a block of columns for purifying atmospheric moisture from the condensate (BKO [Blok kolonok ochistki, Block of purification columns, BPC]) intended for purifying the organic and inorganic foreign bodies from it; the block for conditioning the water designed for decontamination and artificial mineralization of the regenerated water; the drinking water container; the container for industrial water; the block for delivering and heating the water. The block of purification columns (BPC) consists of 5 cylindrical columns with a volume of 1.5 ℓ each. The first 2 columns are filled with a mixed effect filter, the third, fourth and fifth columns are filled with activated carbon. At the input to the system, in the first column of the BPC, a chamber for disinfection is located containing a layer of a granulated sterilizing agent.

The level of requirement for fluid varied and on the average amounted to 1.2--1.4 ℓ for the MC-I and 1.4--1.7 ℓ for the MC-II.

1.5. The Work and Rest Regime in Flight /16

The work capability of the cosmonauts in long term flights mainly is determined by the work and rest regime, the efficiency of setting up the cycle of "sleep-wakefullness." A breakdown in this cycle and degeneration of the usual system of time sensors are factors in the development of a primarily caused phase disagreement in circadian (around the clock) rhythms of the organism, a primary desynchronization. The unusual 24 hour routine used in a number of space flights was an unquestionable factor in desynchronization of the 24 hour rhythm. A previous work and rest program for the cosmonauts often was constructed in such a way that their sleep was combined with periods of flight outside the zone of radio contact, that is, with "dead" turns. The latter, due to precession of the orbit, did not occupy a constant position on the scale of Moscow time and varied from it from day to day. Thus, during the flight of the orbital Salyut-4 station, the cosmonauts lived according to a graph of migrating days.

The first and second main crews of the orbital Salyut-6 and Soyuz complex, with their record flights lasting 96 and 140 days, used a work and rest regime which took into consideration the circadian rhythm of man's organism. The greatest advantage of this regime was the absence of migration of the "sleep-wakefullness" cycle phases along the time axis from day to day. Except for special cases, the periods of sleep coincided with the nocturnal hours of Moscow time.

Several variations of typical 24-hour detailed plans were used. The indices of the day's routine follow:

1	Arise	8.00	
2	Test of the station	8.00--8.20	
3	Morning toilet	8.20--9.00	
4	Breakfast	9.00--9.40	
5	Work	9.40--12.00	
6	Physical exercise	12.00--13.00	
7	Free time	13.00--13.20	/17
8	Work	13.20--14.20	
9	Dinner	14.20--15.00	
10	Free time	15.00--16.00	
11	Work	16.00--17.30	
12	"Tea"	17.30--18.00	
13	Work	18.00--19.00	
14	Physical exercises	19.00--20.00	
15	Supper	20.00--20.30	
16	Free time	20.30--23.00	
17	Sleep	23.00--8.00	

According to a typical routine for a day in different types of activity the following total 24 hour expenditure of time was planned (on the average):

1 Sleep--9 hours 00 minutes.

2 Morning toilet--0 hours 40 minutes.

3 Physical excercises--2 hours 30 minutes.

4 Meals--2 hours 20 minutes.

5 Free time--2 hours 00 minutes--2 hours 30 minutes.

6 Communication and daily operations--3 hours 00 minutes.

7 Experiments and basic operations--about 5 hours 00 minutes.

The total time of items (6) and (7) amounted to about 8 hours out of 24.

The members of the first main crew, during the first month of flight after 6 days of work had a day of rest. During the second and third months of flight a 6 day cycle was used: there was one day of rest after 5 days of work. The members of the second main crew, after 5 working days had 2 days off (Saturday and Sunday) and the first of these was used for sanitation measures. Thus, for the second main crew the rhythm of life was synchronized with the ground /18 sensors for time not only within the fremework of 24 hours but also on the time scale.

During the flights, specialists in the ground service made an analysis of the crew'swork and rest regime. Basically the data on work capability of crew members, the actual duration of working time and sleep was a subjective analysis of the cosmonauts, transmitted every 24 hours to the appropriate medical supervision post. This information significantly adds to the data of radio conversations and to televised observations.

The most important results of using an optimum work and rest regime in flights was retention of work capability of the cosmonauts at a level adequate for completing the planned programs. The work capability of the cosmonauts of the first main crew of the orbital Salyut-6 and Soyuz complex, in their self evaluation, in the first two months of flight was maintained at a high level. In the third month of flight, they began to evaluate it as satisfactory. During the third month of flight, fatigue was apparent not only at the end of the working day but also in the first half of the day.

The work capability of the cosmonauts of the second main crew of the orbital Salyut-6 and Soyuz complex was, as a rule, good during the course of the entire flight. The fatigue apparent at the end of the working day was eliminated by a nights sleep.

The following is evidence of maintenence of work capability at a fairly high level in both crews:

1. Completing the standard program completely.

2. A number of cases of fulfillment of the planned volume of work ahead of time.

3. Initiated conduct of different additional work, observations and experiments.

The flight engineer of the second crew particularly noted /19 the value of the correct work and rest regime for maintaining high work capability. "Our work capability is good when there is rest and the routine of the day is maintained. We work well with enthusiasm, joy and with satisfaction."

The following are positive moments in planning and carrying out the work and rest routine:

1. The high level of social motivation of the cosmonauts.

2. The report by the crew of the results of the experiments made.

3. Participation of the crews in planning flight programs, advance discussion with the cosmonauts on the plan for the prospective work.

4. Measures of the group for psychological maintenance to get the full value of service from the crews.

5. The positive relationship of the cosmonauts to the routine based on the 24-hour graph tying the periods of sleep to the nocturnal hours of Moscow time.

6. The understanding of the flight director of the significance of medical recommendations in operative correction of the work and rest routine.

Moreover, during both expeditions, the circumstance was apparent that a decrease in work capability in the cosmonauts occurred in different degrees. Some of these factors are:

1. Accumulation of fatigue due to the long duration of the expedition.

2. The large load of the daily and multiday work cycle at certain stages of flight: preparation and accomplishment of "Take-off," docking, undocking, resumption of operations, work with the visiting crews.

3. The characteristics of primary adaptive reactions to weightlessness.

4. The monotony of certain types of standard activities.

5. The episodically planned shifts in the "sleep-waking" cycle, disturbance in the continuity of nocturnal sleep periods. (In view of the clearly negative effect of changes in sleep-wakefullness on /20
the general condition of work capability of members of the crew, this question will be considered separately later on).

As was pointed out above, the total duration of the work time was put together with time taken for daily operations (about 3 hours) and the time in the basic working zone. During the first expedition, the duration of the basic working zone nominally was assumed to be 5 hours. Due to symptoms of an accumulation of fatigue, noted in members of the first main crew, on recommendation of the group of medical supply, three weeks before the end of the flight total working time of the crew was decreased for 8 to 5.5 hours per day.

When the second main expedition crew was operating, the time of daily operations remained unchanged but the basic working period was planned, starting nominally at 4 hours 40 minutes.

The reasons for exceeding the planned duration of basic operations and also the reasons for episodes with lack of time for both expeditions were:

1. Giving assistance in carrying out the program of the visiting crew, who were going through a stage of adaptation to weightlessness.

2. Emotional saturation with the situation when working with the visiting crews.

3. Carrying out initiated work not envisaged in the detailed plans.

4. Nonstandard working routines of separate systems.

5. The absence of documentation onboard necessary for certain operations.

6. Sending from group control a large number of recommendations without calculating the time necessary for realizing them.

The lack of time was particularly marked in the period of joint operations with the visiting crews. Then, the crew members had to use working time set aside in the plan for physical exercise, eating /21
and sleeping.

An important question in constructing the work and rest routine for space flights is regulation of the intervals between separate elements of the routine. For the expeditions on the Salyut-6 it was assumed, in particular that the following are nominal. A break between two sequential meals should be at least 3 hours and no more than 6 hours. Physical exercises are carried out no sooner than 1 hour and 30 minutes after eating (2 hours after dinner) and not later than 1 hour before sleep. The interval between physical exercises should be at least 3 hours. A single shift in time from beginning to end of sleep should be ± 1 hour.

Nevertheless, when carrying out the first and second basic expeditions, several times there were planned significant (up to 5 hours or more) shifts in the "sleep-waking" cycle phase and a disturbance in the continuity of nocturnal sleep. These episodic changes in the routine were caused by necessity to conduct different types of work in different time periods. The ballistic characteristics of orbital flight require, in particular, nocturnal operations for launch, docking, going out into space, etc.

The first main crew fairly strictly used the time designated for nocturnal sleep. The time of initiated observations of meteorological phenomena (silver clouds, etc.) sometimes coincided with periods set aside on the cyclogram for conducting physical exercises, eating, sleeping and preparing for the conduct of basic operations.

The members of the second main crew of the orbital Salyut-6 and Soyuz complex, in the first 30--40 days of flight, noted sleep disturbances persisting in the crew commander sometimes shortening his sleep to 5 hours. Sleep disturbances had an individual character. The commander complained of early wakening and impossibility of falling asleep again after this. The flight engineer noted difficulty /22
in falling asleep.

Later on, thanks to systematic use of the correct work and rest routine during the flight after the 30--40 days, sleep disturbances were singular.

Fulfillment of the work and rest routine by the second main crew was unorthodox. The cosmonauts showed a tendency, within known limits, to independently manipulate the time resources. Instead of the planned eating 4 times in 24 hours, the crew used a 3 times schedule. Sometimes, they did not fulfill the planned physical exercises, particularly on Sundays. However, the crew did not permit great disturbances in the work and rest routine. During the entire flight, the cosmonauts retained an arrangement correct as a whole for observation of the unit moments of work and rest routine.

In order to retain good health and maintain high work capability, the cosmonauts for practical realization of the principles which apply to modern biorhythmologic science, during the flights of the main crews on the Salyut-6 station, constantly analyzed the completion of the work and rest routine by the crews and when necessary, made operative corrections in the work and rest routine of the cosmonauts. Most of the recommendations were directed at excluding shifts in the 24 hour rhythm phase of "sleep-wakefullness" and in prevention of negative results from these shifts dictated by necessity. Completion by the cosmonauts of these recommendations and proposals made it possible with great effectiveness to use the advantages of the work and rest routine based on the 24-hour graph.

1.6. Prophylactic Methods

The complex of prophylactic measures recommended by the MC-II included a number of procedures and methods directed at correcting disturbances in different units of the cardiovascular and motor systems. Here are some of the measures:

-- a flight load suit, which, to a certain degree, compensates for /23
the lack of gravitational load on the skeletal and ligament apparatuses;

-- the application of negative pressure on the lower half of the body (LBNP), which simulates the reactions of the cardiovascular system close to that which occurs in a vertical position;

-- a complex of physical exercises which in a measured way load the motor apparatus of the cardiovascular system and which provide a whole series of prophylactic effects enumerated above;

-- the use of water-soft additives on the day of completion of flight;

-- putting on before launch and wearing after flight the prophylactic G suits.

The complex of physical exercises recommended by the MC-II included exercises on the bicycle ergometer which has 5 degrees of load, from 750 to 1200 kmg/min at 60 revolutions of the pedal (with an increase in the frequency of revolutions, the load can be increased to 2000 kgm/min) and walking and running on the "treadmill." The rate and intensity of locomotion (including the motor, without the motor) were determined by the program of the trainer. The program for exercise was set up on a cyclic principle, 3 days of exercises, the fourth day active rest and the training unit set up for strength and speed properties of the muscle system and its endurance. In the routine for the crew, exercises twice a day are planned, morning and evening, lasting for about [illegible] hour (1 hour 10 minutes to 1 hour 30 minutes each).

During training the intensity of load was judged basically by the verbal response of the crew, as to the time of exercise on the bicycle ergometer (BE) and the "treadmill" (CPT) and the pulse rate (PR) at the end of each of these. On certain selected days (on days 28, 29, 60, 61, 62) for objective control of exercise on the training unit, a recording was made on the memory device (ZU [zapominayushcheye ustroystvo, memory device, MD]), the pulse rate and operating regimes of the training unit with subsequent transmission of the data to Earth. Besides this, the effectiveness of the training was judged according to physiological indices: increase in pulse rate when taking functional tests on the BE, /24
dynamic changes in mass and the volumes of the crura.

The MC-II entered the physical training program on the fifth day of flight after the acute period of adaptation had subsided and the operating procedures for the station had been established. For the first 4 days the cosmonauts worked on the bicycle ergometer for 1 hour per day and then as they adapted to the unusual conditions began the training program on both trainers (twice a day). Later on, the physical training was a hard-and-fast element in the routine for the crew. At their request, the length of physical training was increased to 1 hour 20--30 minutes each. Having increased the limbering up time to 20--30 minutes and included a recovery period in the interval of physical training, the cosmonauts, in addition, intensified the exercises. The PR after completion of the exercises was maintained at a high level by the CC-II for the entire extent of the flight except of the first--second and seventh--eighth weeks (125--140 or more beats per minute). In the FE-II, the PR at the end of the exercises for the entire extent of the expedition was somewhat lower and amounted on the average to 115--130 beats per minute. The changes in PR in separate training programs in both cosmonauts varied within large limits, reaching in the CC-II values at 150--170 and even 180 beats per minute; in the FE-II, 120--140 and even occasionally 160 beats per minute. Recording of the PR and the routines showed that on the twenty eighth day the CC-II worked on the BE with an intensity significantly exceeding that planned: the total work reached 5620 watt minutes.

On the sixtieth day of flight, the CC-II worked on the BE for 86 minutes, and the total work amounted then to 10716 watt minutes, and the PR did not exceed 168 beats/minute (in the first test for half of the work it reached 180 beats/minute). In the FE-II on the twenty-eighth day, the total work was 3760 watt units. On the sixtieth day, the FE-II worked on the "treadmill." In 56 minutes of running with breaks he covered a distance of about 3 km. The average speed of the run was 7--9 km/hr. The pulse rate then did not exceed 104 beats/min. /26

TABLE 1 PROPHYLACTIC MEASURES

-- The physical training exercises on the bicycle ergometer and the treadmill; /25

-- Respectively, for the CC-II and FE-II, on the average for 10 days of flight the exercises for CPT amounted to 18--51 and 23--42 min, on the bicycle ergometer 24--44 and 26--45 min, the total was 42--87 and 51--82 min;

-- Wearing the load "penguin" suits (12--16 hr per 24 hours);

-- Training with application of negative pressure on the lower part of the body (at the end of flight according to a special system);

-- The use of water-soft additives (on the day of completion of flight);

-- The use postflight of prophylactic G suits;

-- Psychological support and organization of leisure (radio meeting with interesting people, family, musical accompaniment to radio broadcasts and sessions, etc.).

In spite of the similarity of recommendations and actual programs for training, their volume, intensity, the approach used in selection of exercise, in members of the MS-II they varied considerably. The CC-II paid particular attention to the state of the muscle apparatus, primarily using exercises to strengthen and reinforce the muscle mass in his opinion. A significant time in the training was devoted to strength exercises with expanders and rubber exercise bands attached to the knobs of the BE attached to the CPT in such a way that using them can produce long term stress on separate muscle groups. These exercises the CC-II fulfilled several times a day. In his words, the total duration of "strength" training daily was 30 or more minutes for him. In the standard exercises on the BE and CPT, the CC-II worked intensely with large loads, with special methods increasing the load properties of the trainer (walking with the motor off, /26 walking with the heels forward [?, word almost illegible in original text], etc.). In the FE-II, the volume of the load and intensity of training was noticeably less; he devoted considerably less time to exercising with the expanders and the rubber exercisors. In this plan, an exception was the period of preparations for work operations in open space when both members of the crew, on recommendations of the specialists, included in the training complex forced exercises for the hands with the expanders and rubber exercise bands in order to improve their static and strength endurance necessary for completing the work outside the station. On the average they devoted about 20 minutes to these exercises done during the training routine and also in free time.

Another prophylactic method which was actively used in the MC-II flight was the flight load Penguin suit which the cosmonauts wore 16 hours a day, that is, practically for all their waking time.

In the last stage of the flight, for prophylaxis of hemodynamic /27
disorders, training was used with the effect of LBNP. The physiological effects caused by the LBNP resulted in redistribution of blood with an increase of load to parts of the body in the decompression zone.

During the flight, the MC-I conducted exercises with the LBNP effect cyclically, for 1.5 hours on the five successive days. (Table 14).

TABLE 14 THE SYSTEM AND ROUTINE INCLUDING THE FIFTH DAY TRAINING WITH THE EFFECTS OF LBNP

Training cycle	Training time						Training days	Cycles used
	5	10	15	20	25	30		
1st	15	20	25	15	25	15	1st	1st, 2nd
2nd	20	25	30	20	30	20	2nd	1st, 2nd, 3rd
3rd	25	30	35	25	35	25	3rd	1st, 3rd, 4th
4th	30	35	40	30	40	30	4th	2nd, 3rd, 4th
5th	35	40	45	35	45	35	5th	2nd, 4th, 5th

Then, 5 typical cycles of training exercises were used consisting of six 5-minute intervals with varying degrees of decompression.

During the 140-day flight, training with LBNP was conducted in two stages. In the first stage of training (lasting up to 20 minutes) they began using, 18 days before completion of flight, every fourth day a day of active rest with the cycle of physical exercises according to the following system:

-- for day 18 -10, -15, -25, -35 mm mercury column
-- for day 14 -15, -25, -35, -40 mm mercury column

-- for day 10 -25, -35, -40, -45 mm mercury column
-- for day 6 -25, -35, -40, -45 mm mercury column

The effectiveness of the training process was controlled according to the EKG indices, arterial pressure and the phlebograms.

In the second stage, LBNP training was done every 2 days for 55 minutes (once a day) according to the following system: /28

-25, -30, -35, -40 mm mercury column for 5 minutes, and then -25, -35, -45 mm mercury colum for 10 minutes and -30 mm mercury column--for 5 minutes.

The cosmonauts for the entire extent of the effect of LBNP remained feeling well. According to the telemetric information data on changes of the cardiovascular system, the loads assumed were adequate.

The prophylactic measures used during the 140-day flight were fairly effective. With an increase in length of flight, members of the crew increased the volume and intensity of physical training; the PR then not only did not increase but even decreased (see the recording data for the MD on the 28th and 6 th days of flight). Similar results were obtained in tests with physical load on the BE, conducted on the 41st and 63rd days of flight. On day 72, the CC-II, upon request by the specialists, demonstrated on television exercises on the CPT. During 10 minutes, the cosmonaut ran with the motor switched on (rate about 140 steps per minute, speed 9 km/hr, ran with the motor switched on, did jumps and squats. The motions were made easily without stress; during the running, the CC-II easily changed to jumping on one foot, holding the other leg behind him with his hands; also he completed 10 squats at a rate of one squat every 1.5 seconds. The single difference in motion in weightlessness was the inadequate accent of the rear kick (in running) and the difficulty in getting up from a deep squatting position (in the squats). The body mass underwent considerably less change in this flight than in other expeditions.

The data of postflight examinations which showed adequately high orthostatic stability in both cosmonauts and a low amount of dysfunction of the muscular periphery are all evidence of the high results of the prophylactic measures (see Section: Study of the Motor Apparatus).

1.7. General Condition of the Cosmonauts /29

The transition to weightlessness was accompanied in almost all 6 crew members (2 MC and 4 VC) by the development of a feeling of congestion of blood in the head and stuffiness in the nose, puffiness of tissue of the face. In some of the cosmonauts in this period, a short term spatial illusion occurred, a decrease in appetite, and also a feeling of discomfort increasing with movements of the head and trunk. The degree of the reactions described was individual and in certain of the cosmonauts there was vomiting occurring after eating. Usually, the vegetative disturbances disappeared during the fourth day. In the MC-I, no vestibular vegetative reactions were detected, the feeling of congestion of blood in the head and stuffiness in the nose was only slight (days 1--6). The feeling of blood congestion in the head although it levelled off at the end of the first week of flight, nevertheless, as happened to the MC-I, was noted in decreased form for the entire extent of the flight and increased at the end of physical work, with fatigue, and also caused a need for a large quantity of fluid. The fatigue which developed during the working day usually was completely cured by a night's sleep.

During the flights, slight illnesses and poor health occurred. In the 96-day flight, in one of the cosmonauts on the 50th day, poor health was noted, diagnosed as a cold which was treated with the first aid kit on board. In this same flight, in the third month, the appearance of headaches in both cosmonauts was noted as well as an unpleasant sensation in the region of the heart in the FE-I which involved lack of sleep. Finally, in the 96-day flight, problems with the teeth also arose.

In the 140-day flight, the CC-II on the 21st day developed paronychia of the middle finger of the left hand after taking a blood sample. The treatment was with antibiotics, sulfamides and locally syntazol ointment. On the 49th day of flight, the CC-II reported the occurrence of brief unpleasant sensations in the region of the heart, /30
without irradiation, which disappeared independently and were not repeated. In the FE-II, retrospectively left sided otitis was diagnosed in the middle ear with symptoms of pain in the ear on day 112 of flight. For treatment an alcohol warm compress was used.

Also small everyday injuries occurred in the form of bruises of the fingernail phalanx of the right thumb in the FE-II on the 39th day and a bruise of the left talocrural vessel in the CC-II on the 47th day of flight which were received when working on the bicycle ergometer. Treatment was not required. In both cosmonauts of the MC-II on the 29th, 39th and 53rd days of flight, there were headaches involving, in their opinion, an increase in CO_2 in the atmosphere above 5 mm mercury column (up to 6--7 mercury column). Due to this, in the future an increase in content of CO_2 above 5 mm mercury column was not permitted in the atmosphere.

In the 140-day flight, mainly in the FE-II, one observed a periodic selective decrease in appetite for certain products.

The sleep of the MC-I, as a rule, was good; they fell asleep rapidly and sometimes dreamed. The duration of sleep in the MC-I on the average was 7.5--8.0 hours. However, with joint operation with the VC and when carrying out initiated work, the sleep time was shortened. During the 140-day flight, the characteristics of sleep showed earlier wakening by the CC-II (particularly at the beginning of flight) with subsequent difficulty in falling asleep and late falling asleep by the FE-II. In general, these characteristics of sleep aggravated in flight had occurred on Earth and had practically no effect on work capability. On the average, the duration of sleep in the first 7 weeks of flight amounted to: for the CC-II, 4--6 hours, for the FE-II, 8 hours. Later on, one noted a tendency toward normalization of sleep and longer sleep for the CC-II. However, the CC-II sometimes continued to wake up early. As a soporific, the CC-II several times took eunoktin (it caused headaches and a feeling of poor health) and also the tranquilizer phenibut.

During long-term flights, significant changes in the nervous and psychological sphere did not occur. However, in certain periods of the flight, one observed symptoms of asthenia (fatigue at the end of the working day, drowsiness, the "performance effect" of lack of sleep and rare emotional flare ups at imprecise types of transmission of information), which was somewhat more marked in the MC-I. After landing (in the landing area) the cosmonauts noticed weakness, fatigue, a feel of increased weight of the body and the environmental objects, a gravitational shift in the internal organs in the direction of the gravitation vector and vertigo. With sharp movements of the head in the CC-II and FE-II, during evacuation from the landing area, a feeling of vestibular discomfort occurred. /31

During examination immediately after flight, paleness of the skin was noted and puffiness of the face, limitation in the locomotor function, a decrease in orthostatic stability (in the MC-I commander after 2--3 minutes of remaining in a vertical position a precollapse state developed). The inflated G-suit had an adequate protective effect on the day of landing.

Later on, the condition of the crew progressively improved and motor activity expanded. Thus, even in the first days after the 140-day flight (that is, after a night's sleep) the phenomena of vestibular discomfort disappeared in the CC-II, walking became more stable and the crew independently went to meet the director.

PART II

STUDY OF THE CARDIOVASCULAR SYSTEM

Studies of the central and peripheral hemodynamics was first begun during flights on the manned flight program on the Salyut orbital stations. During manned flights according to the Salyut-6 and Soyuz orbital complex program, the studies of hemodynamics were continued. Here, for correlation of the results, both methods used earlier (measurements of arterial pressure with a tacho-oscillograph method, studies of the phase structure of the cardiac cycle according to a kinetic-cardiogram, determination of venous pressure in the jugular vein, etc.) and a number of new methods were used. In the first place, this is a method of tetrapolar rheography which makes it possible to obtain indices which characterize the pulse blood filling of the head and extremeties, and also to determine (by a calculation method) the cardiac output. Also a method of occlusive plethysmography was used for determining the volume of blood flow and venous pressure in the region of the crus. /33

The studies were conducted preflight, in-flight and postflight at rest and also using functional tests (a test with physical load and LBNP). Also in-flight studies were made of the bioelectrical activity of the myocardium at the 12 standard contact points and a dynamic (continuous recording for 24 hours) electrocardiograph. Besides the traditional methods, preflight and postflight, an echocardiographic method was used.

2.1. A Study of Hemodynamics and the Phase Structure of the Cardiac Cycle in Flight at Rest and when Fulfilling Functional Tests. /34

2.1.1. Method.

Medical studies under conditions of orbital flight were accomplished using the Polinom, the Rheograph-2 and the Beta equipment.

The Polinom instrument is a polygraph with a set of indicators representing three programs.

The first program was used for electrocardiographic examination of the twelve standard contact points.

The second program is designed for studying the phase structure of the cardiac cycle and hemodynamics with recording of the femoral artery pulse (FAP), kinetic cardiograms (KCG), tacho-oscillograms (TO) with pressure markers in the compression cuff (PM).

The third program makes it possible to conduct mechanoplethysmographic and complex sphygmographic studies with recording of electrocardiograms at two standard contact points, mechanoplethysmograms of the crus with compression of the vessels of the femur, a sphygmogram of the carotid and radial arteries, and also a phlebogram of the right jugular vein.

The Rheograph-2 instrument is constructed on a tetrapolar principle. The peculiarity of this rheograph is that it is possible to record a rheographic curve, whose amplitude (Ax) reflects the value of the alternating component of impedance (ΔR) and a calibrated signal (K), proportional to the value of the constant component of the impedance (R). In accordance with this set of instruments, determination of the indices of pulse blood filling of the regional vessels (PPK [pokazatel' pul'sovogo krovenapolneniya, index of pulse blood filling, IPB] = $\frac{\Delta R}{R}$) is done by finding the value of the ratio of amplitude of the rheogram to the calibration signal ($\frac{\Delta R}{R} = \frac{A}{K} \cdot$ const.); (the value const depends on the area studied and for the rheogram of the torso amounts to $30 \cdot 10^{-4}$; for the rheogram of the forearm, the crus and head $10 \cdot 10^{-4}$).

Establishment of the necessary amplitude and range of measurements is done by changing the position of the switch /35
for operating regimes of the instrument. For changing the designated ranges ahead of time, multiple studies were conducted on a simulator of a tetrapolar rheograph similar to the design but with the difference that regulation of amplification and measurement of constant and variable components of impedance is done according to the standard method. The data obtained on the ranges of values of R and $\frac{\Delta R}{R}$ for different areas was applied to the system of the instrument. The instrument has two functional channels and this makes it possible to record a rheogram of the torso, the forearm and crus (simultaneously), the right and left hemispheres of the brain (simultaneously).

The Beta instrument makes it possible to record an electrocardiogram using a zonal system of fixing the electrodes and sensors at the DS contact point, a pneumogram by means of an angular tubular sensor placed above the epigastral region, a seismocardiogram in the region of the apex beat.

In-flight studies include an analysis and evaluation of the following:

-- frequency and rhythm of cardiac contractions;

-- electrocardiograms at 12 contact points;

-- phase structure of the cardiac cycle;

-- arterial pressure;

-- a rheogram of the region of the brain, crus and forearm;

-- the stroke volume of the heart and the minute volume of blood circulation;

-- the rate of expansion of the pulse wave along the aorta;

-- the volume rate of arterial blood flow, the expandability and contractability of veins and venous pressure of the c⁻us;

-- venous pressure in the jugular veins;

-- indices of pulmonary ventilation.

Studies at rest were made both when conducting special experiments (electrocardiographic, rheographic and mechanoplethysmographic studies) and when recording indices in the initial state before making functional tests. In a number of cases studies were made in conditions of the basic volume immediately after waking on an empty stomach. Then the second program of the Polinom apparatus was used with recording of the indices listed above for hemodynamics. The number and time periods of the tests are presented in Table 1. /36

The rhythm of cardiac contractions was determined according to an electrocardiogram (EKG). In the sections for removal and launch of the transport spacecraft, during travel, with functional tests, the DS contact point was recorded (with fixing of the active electrodes using a zonal system on the right and left side of the thoracic cage along the main axillary line at the level of the fifth intercostal). In certain cases, the frequency of cardiac contractions was counted according to a rheogram, a tacho-oscillogram or a kinetic cardiogram.

The phase structure of the cardiac structure was determined by a method of kinetic cardiography [1], based on recording the biomechanical shifts of the precardiac zone of the chest cage, which occur as a result of changes in shape, dimensions of the heart and different motions of it in the chest cage during the cardiac cycle. The analysis was confirmed by amplitude phase characteristics of the rate curve of vibrations in the range of low frequency. For evaluating the left ventricle, a KCG sensor was fixed in the region of the apex beat; for evaluating the right, in the IV intercostal to the right of the parasternal line. Measurement of the intervals between characteristic beats on the KCG curves made it possible to determine the phase of the full cardiac cycle (Figure 1): asynchronous contraction (AC) (transformation), isovolumetric contraction (IC); the period of ejection (PE) of the blood by the ventricles; protodiastoles (PD); rapid (RF) and slow (SF) filling, isometric relaxation (IR); common diastoles (D) and systoles of the auricle (SA).

Symbols for the Drawing Entitled "Identified Points of a Kinetic Cardiogram when Measuring the Duration of the Phases of the Cardiac Cycle": /39

2 -- coincides in time with closing of the cuspidate valve of the heart at the beginning of systoles of the ventricles;

4'-- is characterized by opening of the semilunar valves and beginning of rapid ejection of blood into the aorta and pulmonary artery;

5 -- determines completion of the phase of rapid expulsion, decrease in the rate of output of blood and beginning of the phase of slow ejection;

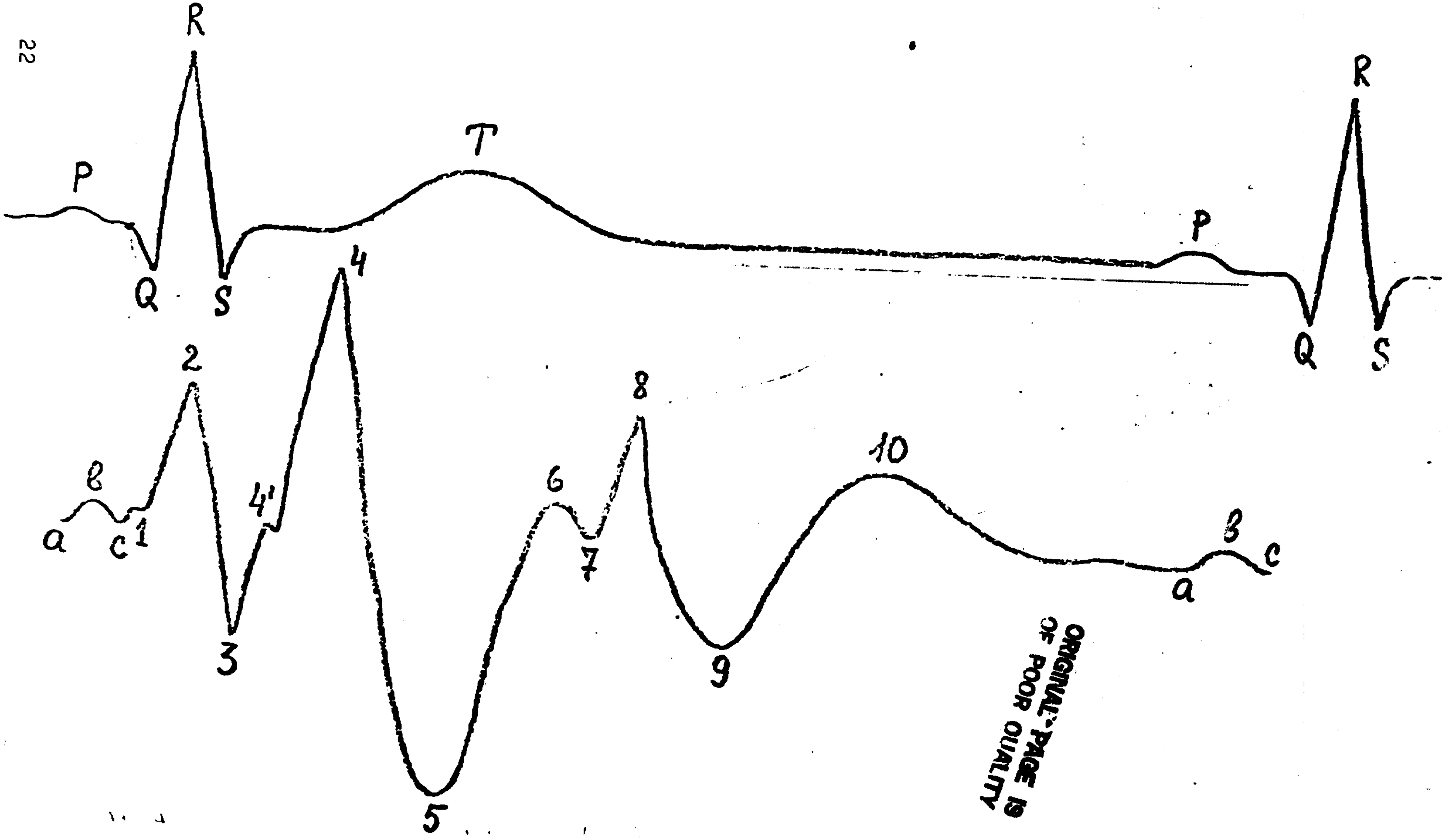


Figure 1: Identified points of a kinetic cardiogram when measuring the duration of the phases of the cardiac cycle.

For symbols see the following pages.

TABLE 1

THE NUMBER AND TIME PERIODS FOR CONDUCTING STUDIES OF THE CARDIOVASCULAR SYSTEM DURING FLIGHT IN CONDITIONS OF REST

STUDIES	EXPEDITION I		EXPEDITION II	
	Flight day number		Flight day number	
1. Electrocardiography at 12 contact points	4	7,20,49,70	5	2I,4I,68,II0,I30
2. Phase analysis of the cardiac cycle	II	7,I4,24,30,42, 49,60,70,77, 82,92	I4	6,7,2I,29,4I,50, 62,68,85,97,II0, II9,I24,I37
3. Arterial pressure, rate of propagation of the pulse wave along the aorta, parameters of cardiac output (according to Braemser-Ranke	II	7,I4,24,30,42, 49,60,70,77, 82,92	I0	7,29,4I,50,62,85, 97,II9,I24,I37
4. Rheography REG	6	I4,24,49,60(CC) 77,82,92	8	4(FE),7,2I(CC), 50,68,85,II0,I24, I37
RG of the extremities	I	I4(CC),24(FE), 24(Forearm in the CC)	3	In the CC-2I,68,II0 In the FE-4,63,II9
RG of the torso	6	7,24,42,70,82	8	4(FE),6(CC),2I (CC),29(FE),4I, 63,68,97,II0,II9
5. Occlusive plethysmography	I CC I FE	42 60	2 CC 3 FE	50,97 29,85,I24
Pressure in the jugular veins	5	I4,49,60,77, 92	5	7,50,85,I24,I37
6. EKG_{DS}, PG, SCG	6/5	7,I4(CC),24, 42,70,82	9/6	7,2I(CC),29,4I, 62,68(CC),97, II0(CC),II9
7. Pulmonary ventilation	3	7,49,70	4	2I,4I,68,II0
8. Studies in condition of basic exchange	I	30	7	CC-2,7,33,40,59, 62,II0 FE-2.7.2I.46

SYMBOLS: REG - rheoencephelogram; RG - rheogram; PG - pneumonogram SCG - seismocardiogram; CC - crew member; FE - flight engineer.

7 -- corresponds to the moment opening begins of the semilunar valve of the heart at the end of the ejection period;

8 -- corresponds to the moment of stress of semilunar value and the beginning of a drop in intraventricular pressure;

9 -- defines the end of the drop of intraventricular pressure and opening of the cuspidate valves of the heart, beginning with the phase of rapid filling of the ventricles with blood;

10 -- slowing of the rate of blood flow in the ventricles, settling of pressure between the auricle and ventricle, beginning of the phase of slow filling of the ventricles;

a-b-c -- characterizes the systole of the auricle.

On the basis of these identified points, a number of time intervals are measured: distance from:

-- beginning of Q deflection to point 2 corresponds to the time of the phase of asynchronous contraction (AC);

-- from point 2 to point 4 corresponds to the time of the phase of isometric contraction (IC);

-- from point 4' to point 7 corresponds to the time of the period of ejection of blood from the ventricles (PE);

-- from point 7 to point 8 corresponds to the time of the protodiastole interval (PrD);

-- from point 8 to point 9 corresponds to the time of the phase of /40 isometric relaxation of the ventricle (IR);

-- from point 9 to point 10 corresponds to the time of the phase of rapid filling of the ventricle;

the a-b-c interval corresponds to the time of the auricle systole.

For evaluating the contractile function of the myocardium on the basis of the time intervals obtained of phases of the cardiac cycle, the derived indices are calculated and the required values according to the formula of V. L. Karpman [2]:

-- the voltage period (VP) = IC+AC;

-- the total systole (S_t) = VP+PE;

-- the mechanical systole (MS) = IC+PE;

-- voltage index of the myocardium (VIM) = $\frac{VP}{S_t}$;

-- the intrasystolic index (ISI) = $\frac{PE}{MS} \cdot 100$;

-- the rate of increase of intraventricular pressure $Vi = \frac{APmin^{-5}}{IC}$;

-- average rate of evacuation of the left ventricle $Ve = \frac{SV}{PE}$;

-- S_t must = 0.12·RR + 0.235

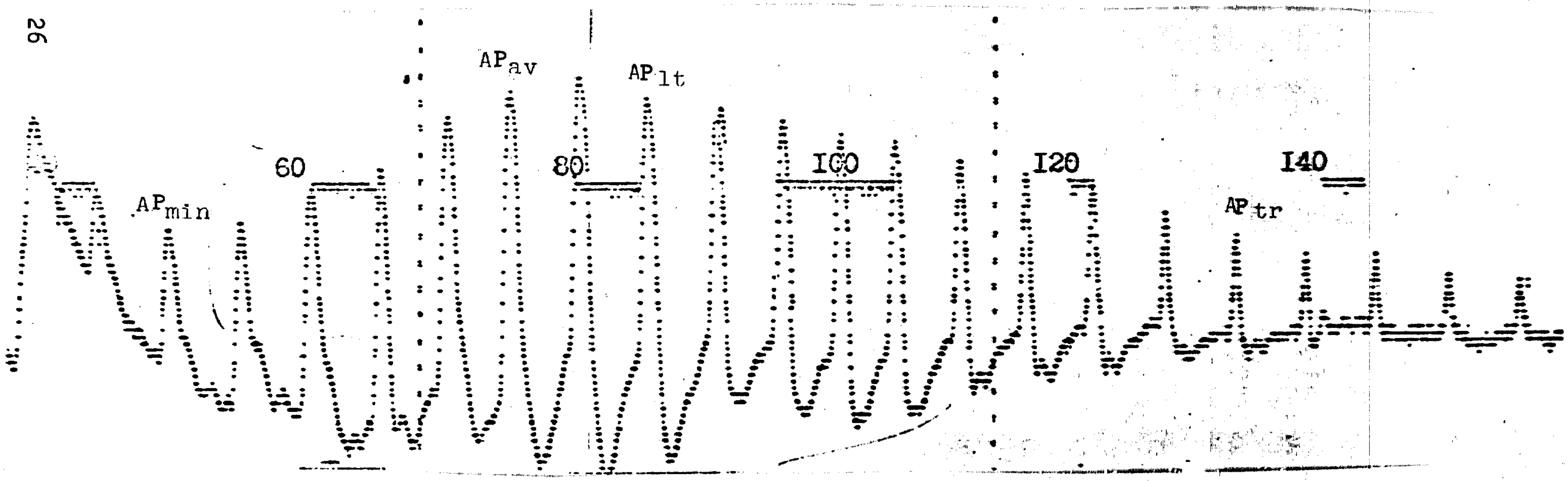
-- PE must = 0.109·RR + 0.159

-- MS must = 0.114·RR + 0.185

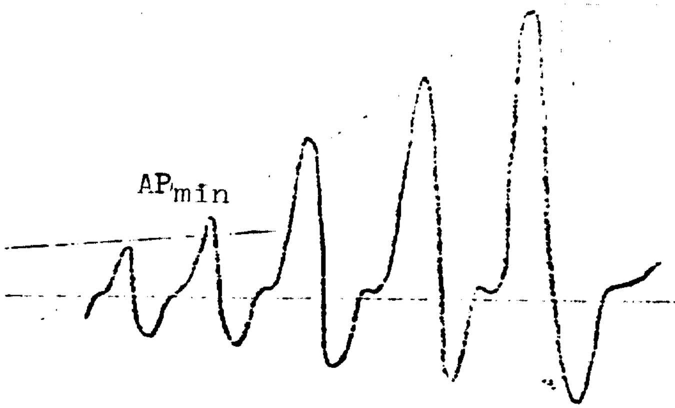
-- ISI must = $\frac{PEd}{MSd}$

Also the relative values of the total diastoles ($\frac{D \cdot 100}{RR}$) were calculated, the filling period ($\frac{VP \cdot 100}{D}$), the phases of isometric relaxation ($\frac{IR \cdot 100}{D}$) and the phase of rapid filling ($\frac{RF \cdot 100}{D}$). Calculation of relative values was to show the change in duration of the total diastole not due to the change in duration of the cardiac cycle and also changes in duration of other indices listed of the diastole not due to changes in duration of the total diastole.

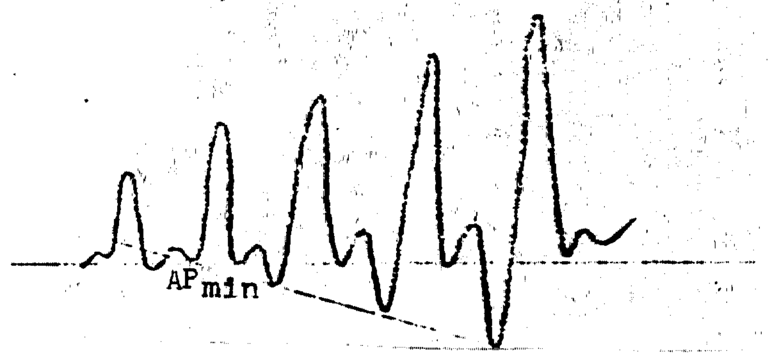
Arterial pressure was measured according to a tacho-oscillograph /41 method proposed by N. N. Savitskiy [3]. Recording of the tacho-oscillogram (TO), which shows a differential curve of the arterial oscillograph was accomplished with even compression of the arm area using a cuff which simultaneously was the receiver for the pulse variations. Measurements of pressure in the cuff were made automatically and simultaneously; the TO curves were recorded as well as compression pressure. Determination of AP parameters was accomplished in the following way (Figure 2): for determining the minimum pressure (Min) the type of tacho-oscillographic curve was calculated. With the predicrotic type (development downward from an isoline of the predicrotic incisura) point calculation of Min was a sharp increase in amplitude of positive oscillations. With the postdicrotic type (development downward from the isoline of the diastole segment; following the dicrotic wave) the point computation was the first clearly marked negative wave. The value of average pressure (Av) was apparent at maximum amplitude of positive oscillations and the formation of ganglionic thickening at the base of the systole rise in the oscillation, that is, at the moment of absence of change of rate of the signal in the walls of the arteries have reached their full contact. The systole pressure showed two components: laterial (Lt) and end (Tr) pressure. The lateral pressure which reflects the moment of closing of the artery only under the effect of forces of the hemodynamic stroke, was determined according to the maximum rate of ejection during the diastole, that is, the first maximum negative oscillation. The terminal pressure which determines the entire energy of the moving column of blood (the total lateral pressure due to conversion of kinetic energy of motion of the stream of blood to pressure) was shown by the sharp change in steepness tangential to the upper and lower levels of oscillation. The presystole wave becomes not ascending but horizontal and weakly



General view of a tacho-oscillographic curve



Predicrotic type of curve



Postdicrotic type of curve

FIGURE 2. Identified points of a tacho-oscillogram for determining arterial pressure.

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expressed. The total amplitude of oscillation then decreases sharply and stabilizes.

The absolute values of arterial pressure are found by dropping a perpendicular from the points found to the mark on the pressure line. The wide mark on this line corresponds to 100 mm Hg pressure. The distance between the marks corresponds to 20 mm Hg. One should consider that recording the TO is done at a rise in pressure on the occlusive cuff. /43

The tonus of the main arteries is indirectly evaluated according to the rate of propagation of the pulse wave along the aorta (RPPWa) which was calculated for the lag time of the pulse of the femoral artery from the moment of opening of the aorta valves fixed on the KCG curve.

The indices of cardiac output were determined by calculation using the Braemser-Ranke physical method [3a] and the A. A. Kedrov rheographic method [4]. The physical method introduces stroke volume into the formulas for calculation:

$$\left(V = \frac{1332 \cdot 0.6Q \cdot PP \cdot S \cdot T}{RPPWa \cdot D}\right)$$

pulse pressure (PP) -- is the difference between lateral and minimum pressures, the duration of the systoles (S), the diastole (D) and the full cardiac cycle (T), the rate of propagation of the pulse wave along the aorta (RPPW) and the area of the cross section of the aorta (Q), determined according to the Suter table [5]. The coefficients 1332 and 0.6 are, respectively, the multiplier for converting pressure into dynes and the correction factor.

The minute volume (MV) was calculated by multiplying V and FCC.

The specific peripheral resistance (SPR) was calculated according to the formula:

$$SPR_f = \frac{\text{average pressure x surface of the body}}{\text{MVC}}$$

The required specific peripheral resistance (SPR_d) was determined according to the formula:

$$SPR_d = \frac{\text{APav required x surface of the body}}{\text{MVC}}$$

Further the ratio is calculated: $\frac{SPR_f}{SPR_d} \cdot 100\%$.

Rheographic studies include a sequential recording of rheograms of the right and left hemispheres and the front-mastoid contact points, longitudinal rheograms of the forearm and crus, and also rheograms of the trunk. /44

For recording rheograms of the head, silver laminated electrodes with a dish shape and diameter 1 cm were used; they were installed in

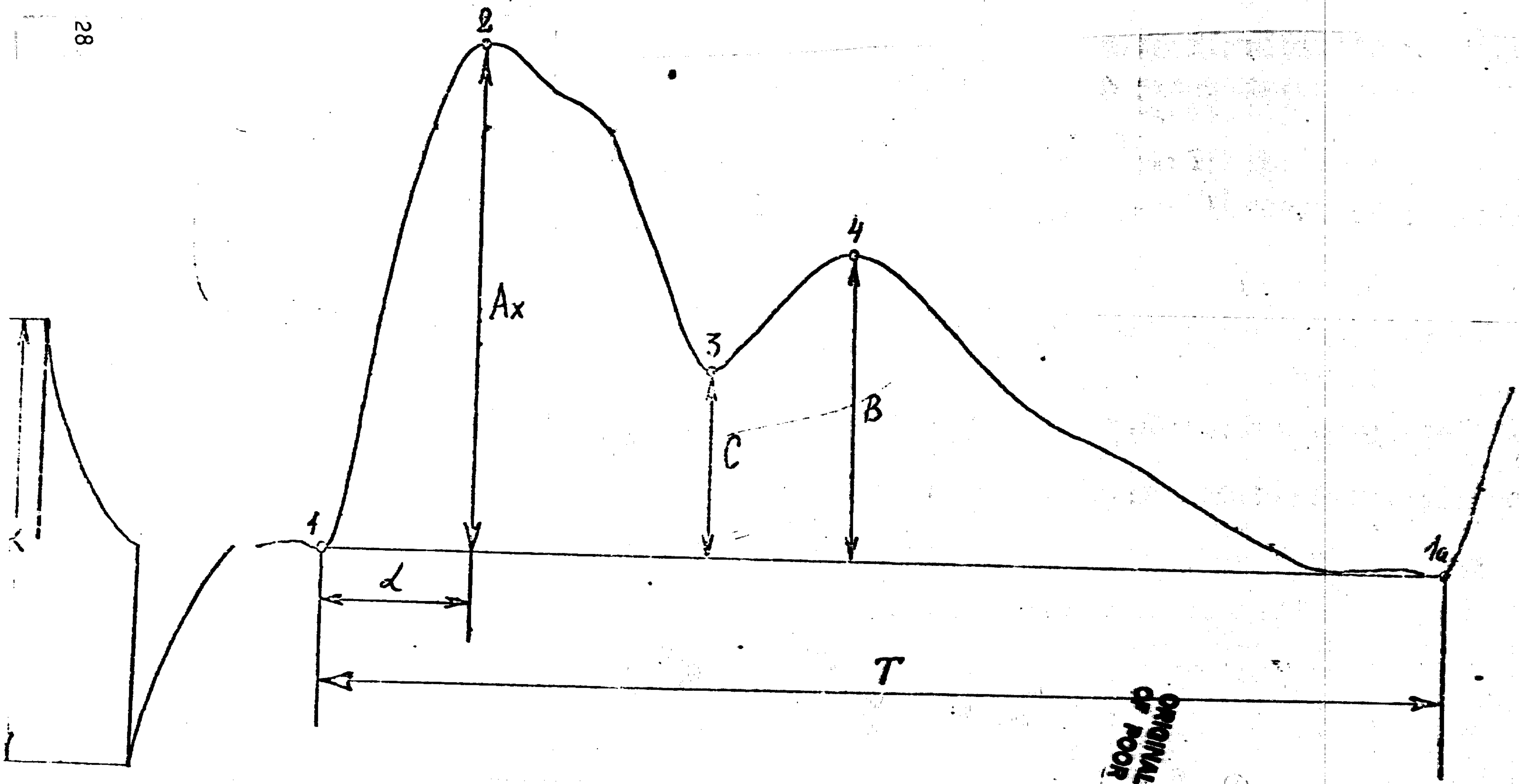

Figure 3. Identified points of a rheogram
For symbols see the following pages.

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a special helmet whose dimensions were selected individually for each crew member. Before applying the electrodes the skin was treated with a hygienic cloth and a current conducting paste was applied.

For recording the rheogram of the trunk and extremities, annular tape electrodes were used made of current carrying plastic 1 cm wide fixed on a plastic band with cloth fasteners. The electrodes on the extremities were located on the forearm 2 cm above the radiocarpal and 2 cm below the ulnar joint; on the crus -- respectively, above and below the talocrural and knee joints. Then, the generator electrode is always a distal amplifier which provides indication by an arrow. The design of all the rheographic electrodes is accomplished in such a way that the cosmonaut independently in 10-15 minutes puts them on with minimum method error.

When decoding the regional rheograms the following were determined (Figure 3): the index of pulse blood filling (IPB) of the vessels in the area studied -- the ratio of constant and variable components of impedance ($Ax/K \cdot 10 \cdot 10^{-4}$) -- the index of minute blood filling (IMB); the index of tonus of the large arteries -- the ratio of duration of anacrotism into the duration of the cardiac cycle ($\alpha/T \cdot 100\%$), the index of tonus of the small arteries and arterial or the dicrotic index (DcI) -- the ratio of amplitude at the level of the incisura to maximum amplitude (in %) and the index of tonus of the veins or the diastolic index (DI) -- the ratio of the amplitude of the dicrotic wave to the maximum amplitude of the curve (in %) [4a]. On the rheogram of the torso, using A. A. Kedrov's formula, the stroke volume of the heart (SV) was calculated as well as the minute volume of circulation (MVC).

Symbols for the Drawing Entitled "Identified Points of a Rheogram". /46

1 and 1a -- start of the rapid rise of the rheographic curve;

2 -- the point of maximum rise of the systole part of the rheographic wave;

3 -- the point located at the level of the incisura;

4 -- The point of maximum rise of the dicrotic deflection.

When decoding rheograms the following are determined:

K -- amplitude of a calibrated signal (in mm);

Ax - amplitude of systolic part (in mm);

B -- amplitude of rheogram at the level of the dicrotic wave (in mm);

C -- amplitude of rheogram at the level of the incisura (in mm);

α -- duration of the anacrotic (diastolic) phase of rheographic curve (in seconds).

When decoding rheograms the following indices are determined:

$IPB = \frac{Ax}{K} \cdot 10 \cdot 10^{-4}$ -- is the index of pulse blood filling (IPB);

$IMB = IPB \cdot FCC$ -- is the index of minute blood filling (IMB);

$\frac{a \cdot 100}{T} \cdot 100\%$ -- is the index of tonus of the large arteries;

$\frac{C \cdot 100}{Ax}\%$ -- is the dicrotic index -- an index of tonus of small arteries and arterials (DcI);

$\frac{B \cdot 100}{Ax\%}$ -- the diastolic index -- is the index of vein tonus (DI);

$SV = \frac{Ax}{K} \cdot 30 \cdot 10^{-4}$. Body weight in gr. 0.7;

$MVC = SV \cdot FCC$.

Measurement of venous pressure in the jugular vein was done by an indirect method based on the effect of disappearance of elements of the venous pulse (wave a) (Figure 4) on a venous arterial pulsogram (VAP) with the LBNP effect [6]. During a background (Earth) examination, this effect was determined by rotating the body in the frontal plane and venous pressure was calculated according to the formula:

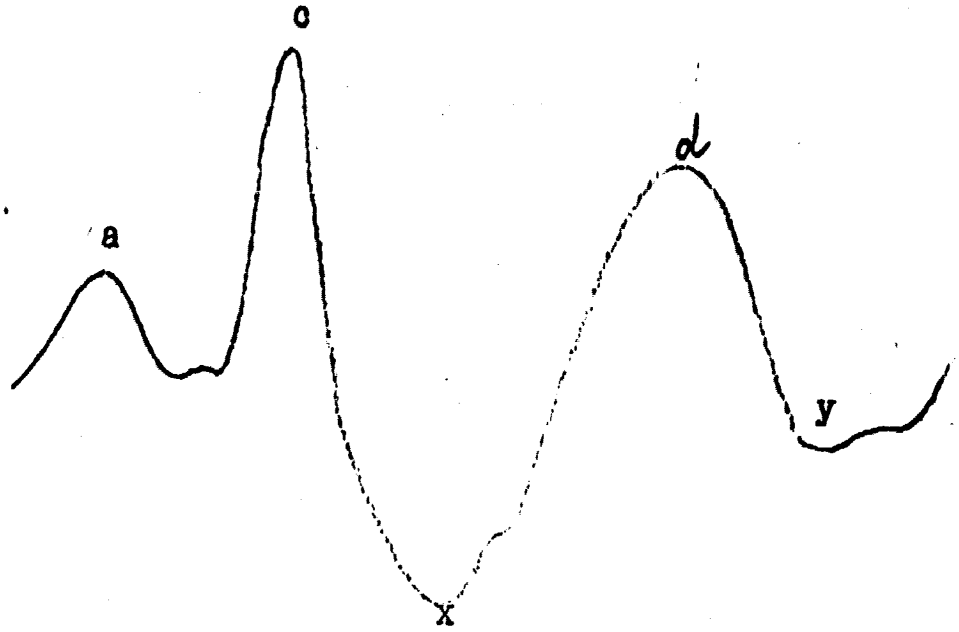
$VP_f = \frac{\ell \cdot \sin \alpha}{13.6}$, where ℓ -- is the distance in mm from the right auricle to the plane passing through the parietal field, $L\alpha$ -- is the angle of rotation of the table. For determining VP and LBNP conditions, one defines the transition coefficient (K). To do this, as a result of the orthostatic effect, a vacuum was created (Vc), in which the moment of disappearance of the a wave was defined and the coefficient of K was calculated according to the formula: /47

$$K = \frac{VP_f}{Vc}.$$

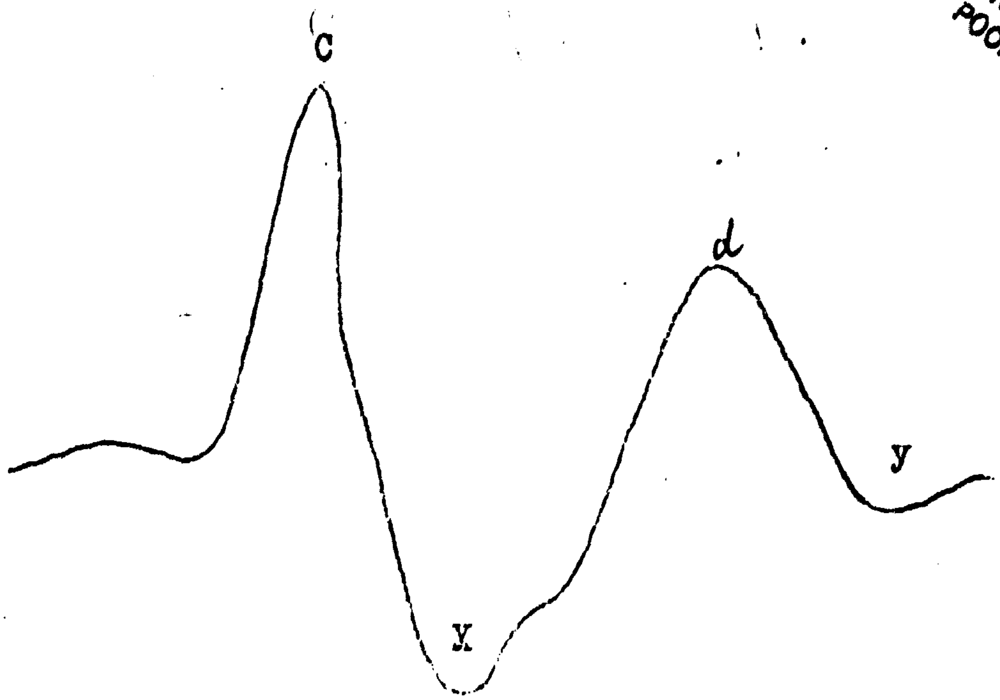
Venous pressure in flight also is determined according to the LBNP value which causes leveling off of the a wave on the VAP, multiplied by the value of K: $VP = Vc \cdot K$.

A method of occlusive plethysmography [6a] was used for determining the rate of blood fill of the crus, the expansion and contraction of the veins and venous pressure. For evaluating the changes in volumetric values of inflow of blood to the crus, calibration of the PLC was done. In the measuring cuff, using a calibration device in the form of a syringe, sequentially four portions of air 10 ml each were supplied. Then the amplitude was measured (in mm) of the calibration signals corresponding to introduction into the measuring cuff of 10, 20, 30 and 40 ml of air. According to the data obtained, a calibration graph was constructed (Figure 5) and for its future use ℓ_2 was converted from millimeters to milliliters.

During the study, a compression cuff is placed on the lower third of the femur, and a measuring cuff in the area of m. gastrocnemius. The curve of change in pressure in the measuring cuff is recorded;



Normal type of curve.



Disappearance of the a wave.

Figure 4. Identified points of a venous-arterial pulsogram.

For symbols see the following page.

Symbols for the Drawing Entitled "Identified Points of a Venous-Arterial Pulsogram". /50

a wave -- the positive wave during an auricle systole as a result of a.. increase in volume of neck veins due to a lag in blood flow to the right auricle

systolic collapse X -- forms as a result of improvement in flow from the neck veins during a relaxation of the myocardium of the auricle and a shift in the atrial ventricular membrane during evacuation of the ventricle

c wave -- transmission pulsation of the carotid artery

d wave -- a positive wave during isometric relaxation of the ventricle when the atrial ventricular membrane shifts upward and increases pressure of inflow of blood to the right auricle

diastolic collapse y -- drop in the curve in the phase of rapid filling of the ventricles leading to improvement in blood outflow.

this reflects the dynamics of the volume of the crus. By inflating /47 the measuring cuff at the initial stage under manometer control, by stages, the following pressures are created: 5, 7.5, 10.5, 12.5, 15 mm mercury column. Then, compression of the vessels of the femur is accomplished. Pressure which causes visible rise in the curve corresponds to pressure in the veins. When carrying out an occlusive test, the value of compression pressure is defined as the total: venouse pressure + 15 mm mercury column. Recording of the PLC is done with one of the physiological indices according to which FCC is calculated. On the curve of the plethysmograph, (Figure 5) the following /48 were measured: time from start of the rise of the curve to its entry on the plateau (t_1 s), maximum amplitude of the plateau level (ℓ_2 in mℓ), time from start of the release of pressure in the cuff to intersection with the isoline (t_2 s) and the following indices were calculated:

-- the rate of blood filling vessels of the crus $V_{t1} = \frac{\ell_2(m\ell)}{t_1(s)}$

-- pulse rate of blood filling of crus $V_n = \frac{\ell_2(m\ell)}{FCC(beats)}$

-- the rate of outflow of blood from the crus vessels:

$$V_{t2} = \frac{\ell_2(m\ell)}{T_2(s)}$$

For determining the volumetric rate of blood flow the following formula is used:

$$V_o = \frac{V_{t1} \times 60 \times 100}{w} \text{ (cm}^3\text{/100 cm}^3\text{tissue/min)},$$

where w -- is the volume of the crus in cm^3.

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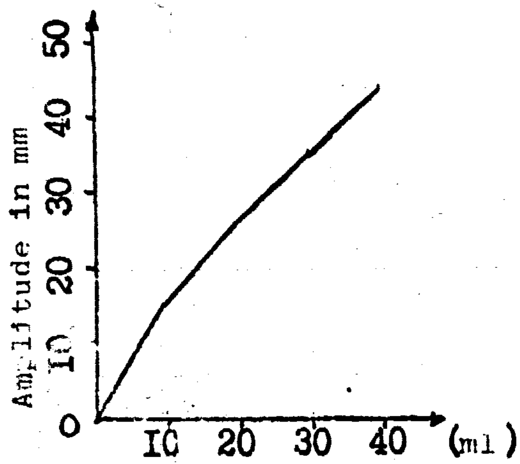

Calibration graph of the calibration signal

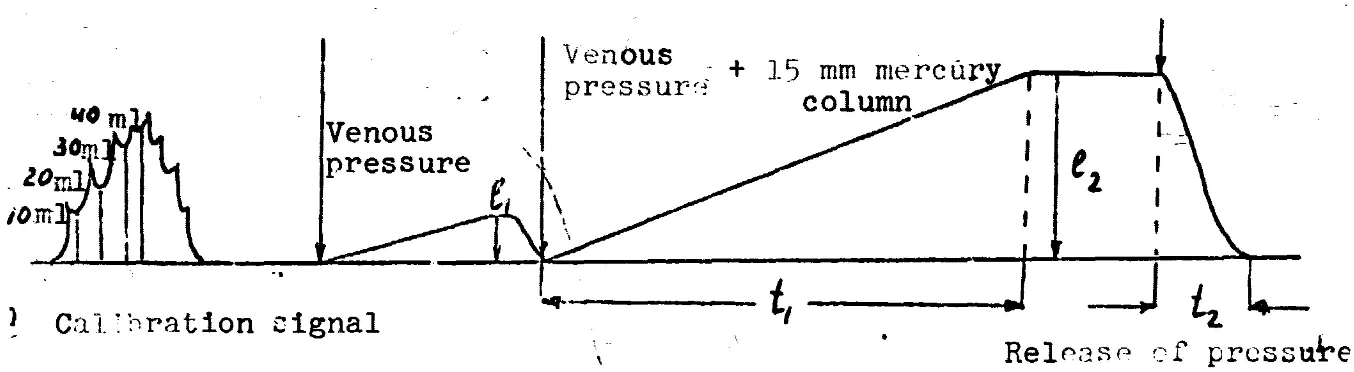

Figure 5. Change in the plethysmogram of the crus with compression of the vein by an occlusive cuff.

Conventional symbols:

ℓ_1 increase in PLC with minimum occlusive pressure (mm) -- for determining venous pressure;

ℓ_2 maximum amplitude of PLC at the plateau level;

t_1 - time (in seconds) from the start of rise of the PLC curve to the plateau;

t_2 - time (in seconds) from the start of release of pressure in the cuff to intersection with the PLC curve and the base line.

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When interpreting the data, the following indices were obtained using the indicated method:

t_1 and ℓ_2 characterize the state of tonus of venous vessels and the degree of expansion of the venous reservoir;

V_{t1}, V_o reflect arterial inflow to the vessels of the crus;

V_{t2} characterize the reactivity of venous vessels of the crus and the conditions of outflow of venous blood from the crus to the proximal section, that is, the contractibility of the veins.

Recording of pulmonary ventilation was done using a turbine type sensor fixed at the output of the mask. The number of full respiratory pulses was measured each of which equalled 0.5 ℓ per 1 min and the minute volume of breathing was determined (MVB).

The vital capacity of the lungs (VCL) was determined in liters for maximum intake.

A test with the effect of LBNP was carried out using a pneumatic /52 vacuum suit put on the lower half of the body and hermetically sealed at the level of the ilium ridge. The test with LBNP was conducted in the following sequentially created evacuation conditions: -45 mm Hg pressure 10 s (in order to determine pressure in the jugular veins); -25 mm Hg pressure 2 min; -35 mm Hg pressure 3 min. In the initial state before evacuation, during evacuation and in the recovery period, the following indices were recorded continuously:

-- a rheoencephalogram with both hemispheres of the brain (REG);

-- the curve of the pulse of the femoral artery (FAP);

-- A kinetic cardiogram in the field of the apex beat (KCG) (except for certain moments when the CCG was switched over to the vein-artery pulsogram).

Periodically, approximately once a minute, a tacho-oscillogram (TO) was recorded for the rise and release of pressure in the compression cuff placed on the arm.

In the preflight period, four tests were made with each cosmonaut and five tests were made during flight. In the members of crew I, on days 14, 49, 60, 77 and 92, and in members of crew II on days 7, 50, 85, 124 and 137. The test with measured physical load on the bicycle ergometer was conducted with a value of the work 750 kgm/min (at a pedaling rate of 60 revolutions per minute) for a period of 5 minutes. Before and after the work, the following indices were recorded: a rheogram of the torso with the electrodes placed on the upper third of both arms (RG_{torso}), CCG in the area of the apex beat, FAP, TO, a seismocardiogram (SCG), a pneumogram (PG), an electrocardiogram at the DS contact point (EKG_{DS}). During the work, a recording of the

EKG_{DS} and PG was made. The methods for recording and decoding the indices are presented in the section entitled "Methods." Two to three tests were made in the preflight period with each cosmonaut and during the flight of the MC-I, 6 tests (on days 7, 24, 30, 42, 70 and 82) and with MC-II -- five tests (on days 29, 41, 62, 97 and 119).

2.1.2. Results of Studies at Rest and their Discussion. /53

The frequency of cardiac contractions in flight in three of the four cosmonauts usually exceeded the preflight values and in a number of cases at the end of the flight a tendency was noted toward a progressive increase in this index (Figure 6). However, in the CC-I, the frequency of cardiac contractions in flight was, as a rule, below the preflight values or did not differ from them.

The indices of arterial pressure (terminal and lateral systolic, diastolic, average and pulse) changed within small limits and their dynamics were varied in different cosmonauts. The most common principle of change in arterial pressure was a tendency developed in a number of cases at certain stages in flight toward a decrease of all or some of the indices. Thus, in the CC-I and CC-II, all of the indices of arterial pressure in the second month and certain indices (lateral, systolic, diastolic, pulse pressure) in the CC-I in the third month of flight, and also the pulse arterial pressure in the FE-I and FE-II were smaller than the preflight values (Figure 7).

The changes in phase structure of the systole of the left ventricle (LV) in flight in both cosmonauts (MC-2) showed a shortening of the phase of isometric contraction by 22-36% and a tendency toward a decrease or an actual decrease by 5-15% VIM (Table 2). The actual duration of the period of ejection increased in both cosmonauts even in the first month of flight by 8-12% and later on did not differ from the preflight values. The ratio of the actual values of the period of ejection to the required or the entire extent of the flight exceeded the average preflight value (by 4-11%). The duration of the mechanical systole and its ratio to the required value underwent insignificant variations around the preflight level without a definite tendency in change. The intrasystolic index and its ratio to the required value exceeded the average preflight values insignificantly (4-6%). The /57
initial rate of increase of the intraventricular pressure was increased by 19-52% (in the FE at 4 months, by 78%).

The changes in structure of the systole of the right ventricle were apparent for the first 3 months in both cosmonauts with a tendency toward shortening the phase of isometric contractions (by 4-7% in the CC and 10-14% in the FE) and the index of myocardium voltage (only in the CC by 2-7%) with a subsequent tendency toward its increase (the IC in the CC by 7-9%, in the FE by 10%, the VIM in the CC by 5-8%, in the FE by 7-10%). The duration of the ejection period, the mechanical systoles and their ratio to the required value varied insignificantly in the first 1-2 months and later on also had an insignificant tendency toward decrease, as a rule, by 3-9%. The intrasystolic index did not change.

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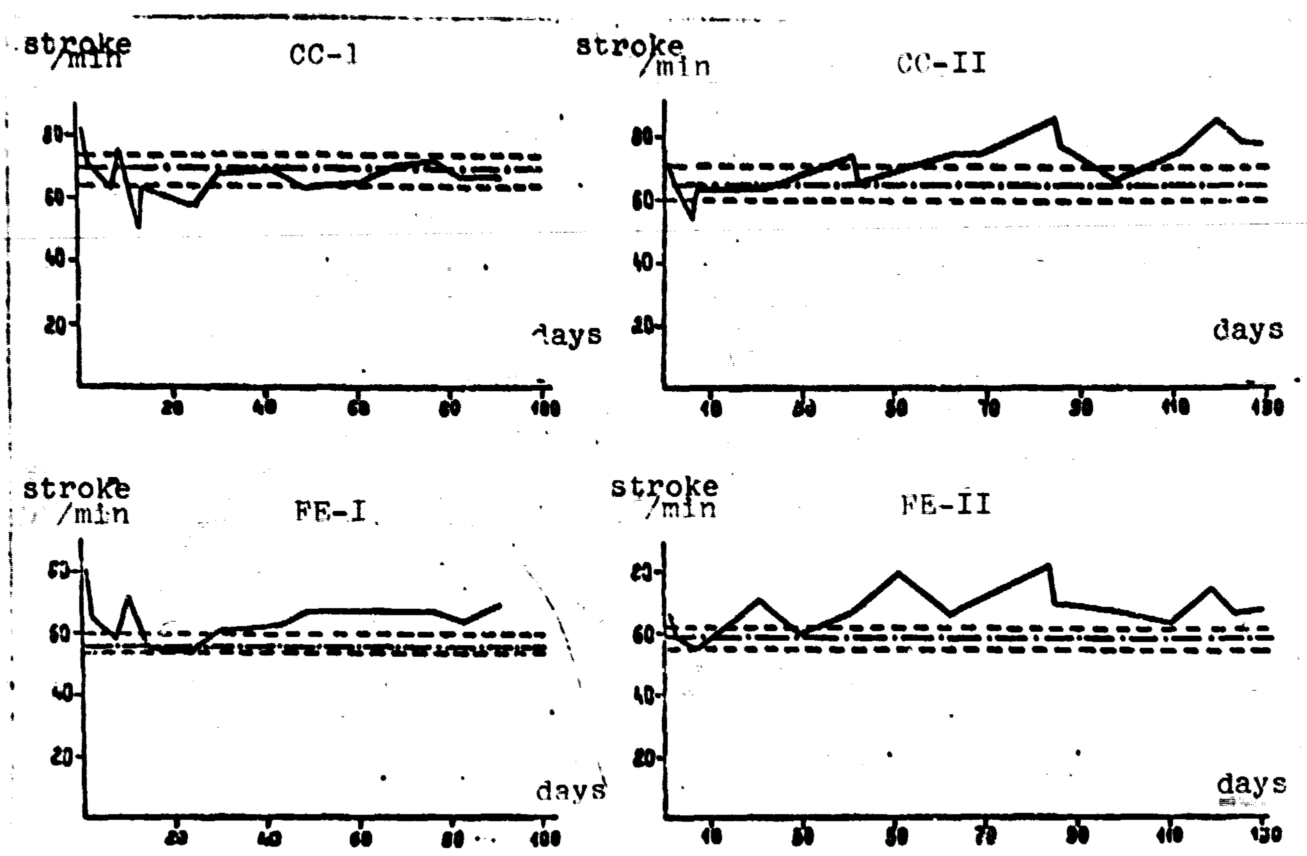

Figure 6. The dynamics of average values of frequency of cardiac contractions in flight symbols:

______ -- actual average values of the index in different periods of orbital flight;
-.-.-. -- average values of the index in the preflight period;
------ -- limits of variation of the index in the preflight period;
CC-I and CC-II -- commanders of the first and second main crews;
FE-I and FE-II -- flight engineers of the first and second main crews.

The data presented indicate that one is observing hyperfunction /57 of the heart on the part of the LV for the entire extent of the flight and this indicates a whole complex of phase shifts, in particular, an increase in the intrasystolic index, and in the first month of flight not only relative but also absolute values of the duration of the ejection period [7]. The power of the cardiac contraction increases (shortening of the IC), effectively its duration expended in completing external work in the form of ejection of blood (increase of PE) with simultaneous shortening of the preparatory work of the heart for ejection of the blood (decrease in VIM which indicates a decrease in the nonproductive activity of the heart [2]).

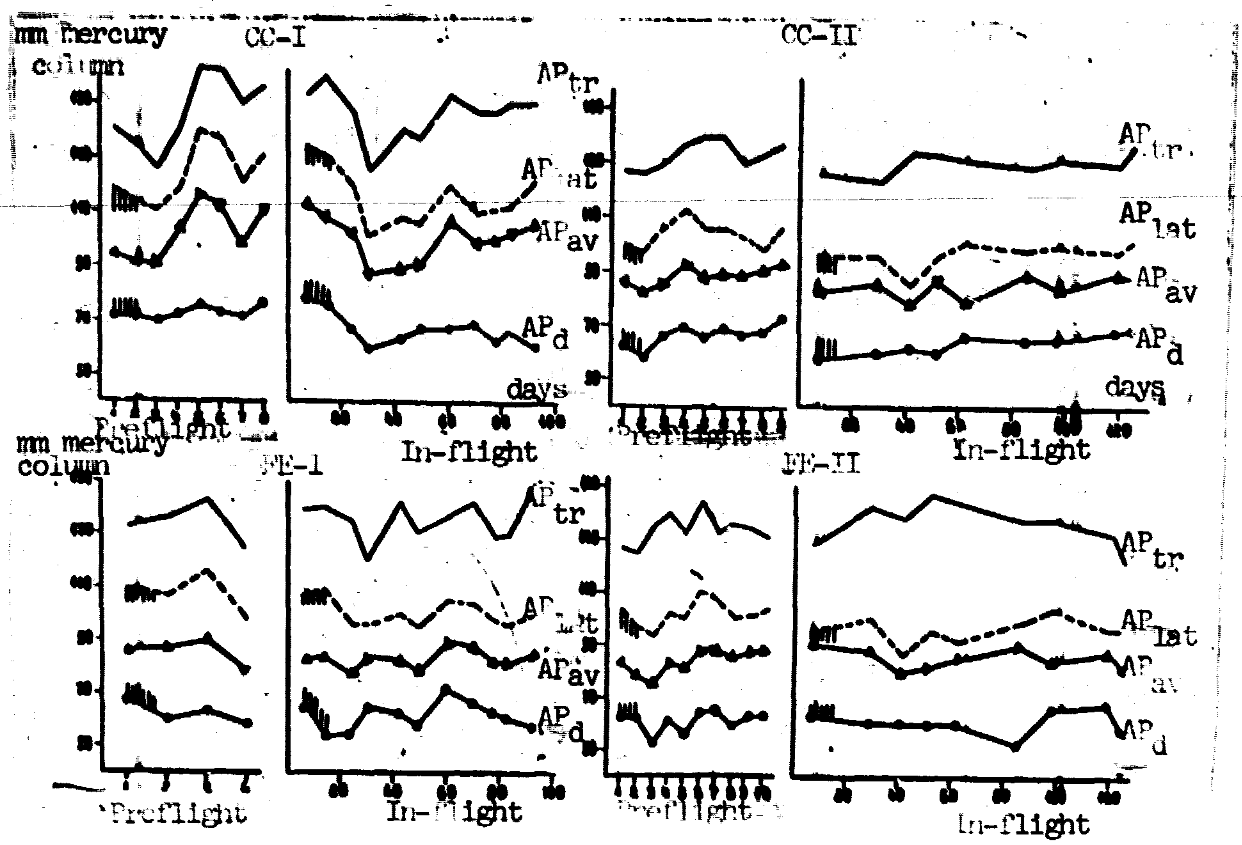

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Figure 7. Dynamics of the indices of arterial pressure in flight.
Symbols:
______ -- terminal systolic arterial pressure (AP_{tr});
\- - - -- Lateral systolic arterial pressure (AP_{lat});
Δ-Δ-Δ- -- Average arterial pressure (AP_{av});
-o-o-o -- Diastolic arterial pressure (AP_d).
Directions of the dashed lines indicate pulse pressure.
CC-I and CC-II -- the commanders of the first and second main crews;
FE-I and FE-II -- flight engineers of the first and second main crews.

The phase structure of the diastole changed depending on the length of the flight (Table 3). The duration of the total diastole, the period of filling and the phase of slow filling changed in the flight in two phases. Other indices of the diastoles (the phase of isometric relaxation, the phase of rapid filling) had a uniform type of change throughout the entire flight. The absolute and relative values of the diastoles of the left ventricle (LV) of the heart during flight primarily increased (in the first month) and then decreased, going beyond the limits of preflight variations in the CC. This decrease, respectively in the CC and FE amounted to: for absolute values of the total diastole 10-26% and 13-19%; for its relative values 7-14% and 3-11%. Then, in the CC one observes a tendency toward a more marked change at the end of th flight. The duration of the filling period and the phase of slow filling essentially increased in the first and to a lesser degree in the second month of flight; later on it decreased /57 /59

TABLE 3

THE DYNAMICS OF THE MEAN VALUES OF BASIC INDICES OF DIASTOLES OF THE LEFT (LV) AND RIGHT (RV) VENTRICLES IN THE 140-DAY FLIGHT

	Indices		Commander Preflight (average)	Commander In-flight (Month) 1	Commander In-flight (Month) 2-5	Flight Engineer Preflight (average)	Flight Engineer In-flight (Month) 1	Flight Engineer In-flight (Month) 2-5
LV	IR (ms)	abs. w.	85	62	42-57	88	50	47-62
		increase		-27	-50- -33		-43	-47 - -30
	PIR* (%)	abs. w.	I7,9	II,9	I0,I-I5,6	I7,2	9,0	II,5 - I5,6
		increase		-34	-44 - -I3		-48	-33 - -9
	VP (ms)	abs. w.	390	460	300 - 340	410	500	310-380
		increase		+19	-22 - -I3		+23	-I7 - -7
	PNP* (%)	abs. w.	8I,9	87,7	84,I - 89,8	82,7	90,6	86,2 - 88,9
		increase		+7	+3 - +I0		+9	+4 - +7
	RF (ms)	abs. w.	4I	79	62 - 86	95	I00	7I - 8I
		increase		+93	+52 - +I03		+5	-25 - -I5
	PBN* (%)	abs. w.	8,7	I5,2	I7,2 - 2I,5	I9,4	I8,5	I6,5 - I9,I
		increase		+75	+97 - +I47		-4	-I5 - -I
	SF (ms)	abs. w.	295	330	I80 - 260	250	340	200 - 240
		increase		+I2	-40 - -I2		+35	-I9 - -4
RV	IR (ms)	abs. w.	46	3I	36 - 48	4I	4I	45 - 64
		increase		-33	-2I - +4		0	+I0 - +57
	PIR* (%)	abs. w.	I0,I	5,0	I0,4 -I2,9	8,9	7,I	I0,7 - I5,6
		increase		-50	+3 - +28		-2I	+2I - +76
	VP (ms)	abs. w.	4I0	600	320 - 420	430	540	310 - 4I0
		increase		+47	-22 - +I		+24	-20 - -5
	PPI* (%)	abs. w.	-89,8	95,I	86,4 -89,7	9I,5	92,8	88,6 - 89,6
		increase		+5	-4 - 0		+I	-9 - -2
	RS (ms)	abs. w.	45	53	67 - 8I	49	66	60 - 90
		increase		+I8	+50 - +79		+34	+22 - +85
	PBI* (%)	abs. w.	9,7	8,7	I7,I - 2I,4	I0,7	II,I	I5,6 - I9,4
		increase		-I0	+76 - +I2I		+4	+46 - +8I
	SF (ms)	abs. w.	300	510	I90-290	3I0	430	220 - 260
		increase		+70	-36 - -3		+33	-30 - -I6

For symbols see the section "Methods".

 *[Translator's note: These abbreviations are transliterated. They are not referred to in the text].

TABLE 2

DYNAMICS OF AVERAGE VALUES OF THE BASIC INDICES OF SYSTOLES OF THE LEFT (LV) AND RIGHT (RV) VENTRICLES IN THE 140-DAY FLIGHT.[1]

Indices		Commander Preflight (average)	Commander In-flight (Mo.) I	Commander In-flight (Mo.) 2-5	Flight Engineer Preflight (average)	Flight Engineer In-flight (Mo.) I	Flight Engineer In-flight (Mo.) 2-5
IC (sec)	Abs. Wt.	0,059	0,046	0,040-0,043	0,058	0,046	0,037-0,045
	Increase		-22	-32 - -27		-2I	-36 - -23
E (sec)	Abs. Wt.	0,284	0,3I8	0,279-0,293	0,282	0,304	0,275-0,296
	Increase		+I2	-2 - +3		+8	-2 - +5
Eph/d* (%)	Abs. Wt.	II0	I2I	II4-II7	I05	II3	II0-II6
	Increase		+I0	+4 - +7		+8	+5 - +II
5 tech* ph/d*(%)	Abs. Wt.	II9	I24	II7-II8	II4	II6	II3-II8
	Increase		+4	-2 - -I		+2	-I - +4
ISF (%)	Abs. Wt.	84	87	87-88	83	86	87-88
	Increase		+4	+1 - +5		+4	+5 - +4
ISI ph/d*(%)	Abs. Wt.	94	98	98-99	93	98	97-99
	Increase		+5	+5 - +5		+6	+5 - +6
VIM (%)	Abs. Wt.	30,2	25,4	27,2-28,6	28,4	27,5	25,I-26,9
	Increase		-I6	-I0 - -5		-3	-I2 - -5
	Abs. Wt.	I06I	I260	I2I4-I344	932	I232	II56-I656
	Increase		+I9	+I4 - +46		+32	+24 - +78

*[Translator's note: These abbreviation are not referred to in text].

and in the CC this decrease progressed depending on the duration and at the end of the flight amounted, respectively, to 22 and 40%; in the FE, these indices decreased by 17 and 19%. The relative value of the filling period in both cosmonauts increased by 3-10% and in some cases exceeded the preflight variations.

The phase of rapid filling of the left ventricle was characterized by different types of change: in the CC, it increased by 52-109% and in the FE decreased by 15-25%. The absolute and relative values of the phase of isometric relaxation of the left ventricle decreased in both cosmonauts in different flight periods by 9-50%.

[1] [Translator's note: Commas in tabulated material are equivalent to decimal points in this Table and throughout the text]

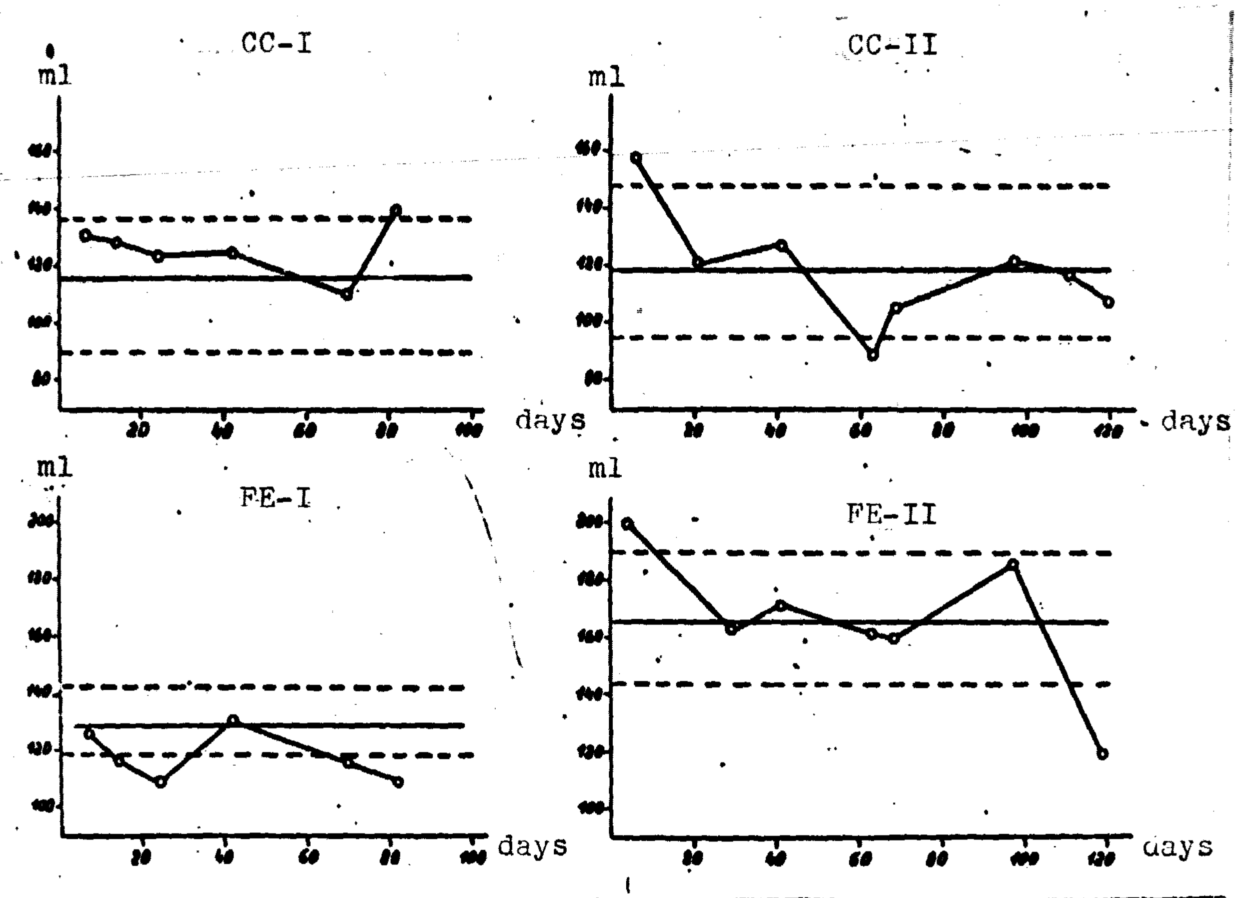

Figure 8. The dynamics of stroke volume of the heart in flight.
Symbols:
o-o-o - Actual values of the stroke volume of the heart in different periods of orbital flight;
_____ - the average value of the stroke volume of the heart in the preflight period;
- - - - limits of variation in the stroke volume of the heart in preflight period;
CC-1 and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

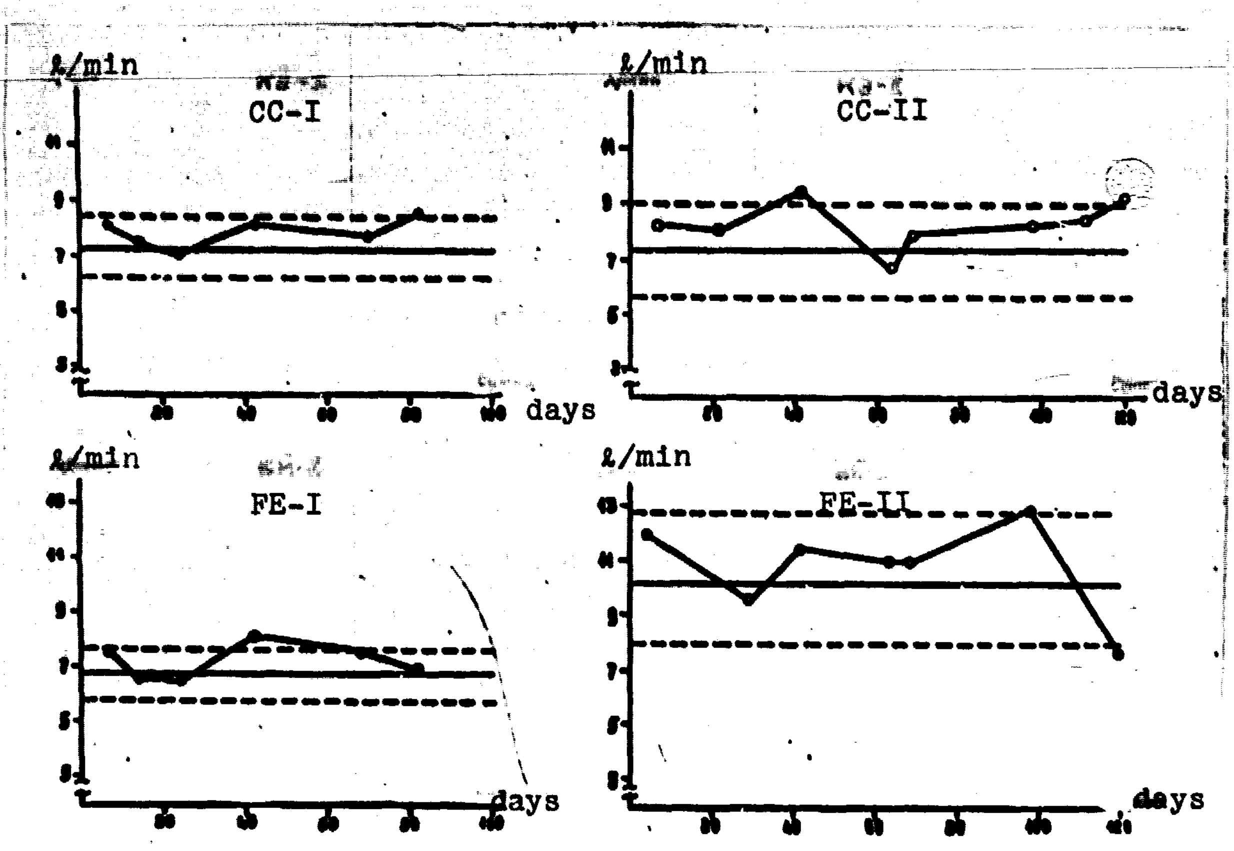

Figure 9. Dynamics of minute volume of circulation in flight.
Symbols:
o-o-o - actual values of minute volume of circulation in different periods of orbital flight;
_____ - average value of minute volume of circulation in the preflight period;
- - - - limits of variation of minute volume of circulation in the preflight period;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

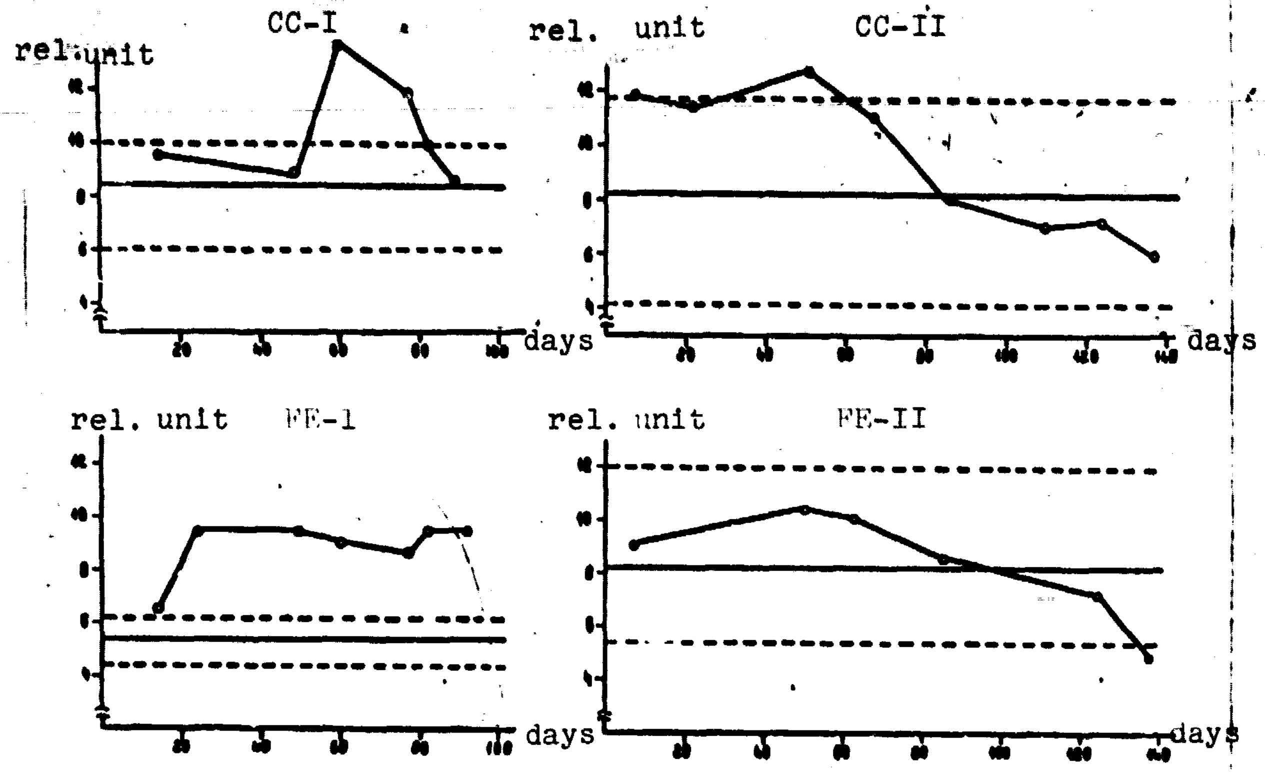

Figure 10. Dynamics of the index of pulse blood filling of the vessels of the head in flight.

Symbols:

o-o-o - actual values of the index of pulse blood filling of the vessels of the head in different periods of orbital flight;

_____ - the average value of the index of pulse blood filling of vessels of the head in preflight period;

- - - - limits of variation of the index of pulse blood filling of the vessels of the head in the preflignt period;

CC-I and CC-II - commanders of the first and second main crews;

FE-I and FE-II - flight engineers of the first and second main crews.

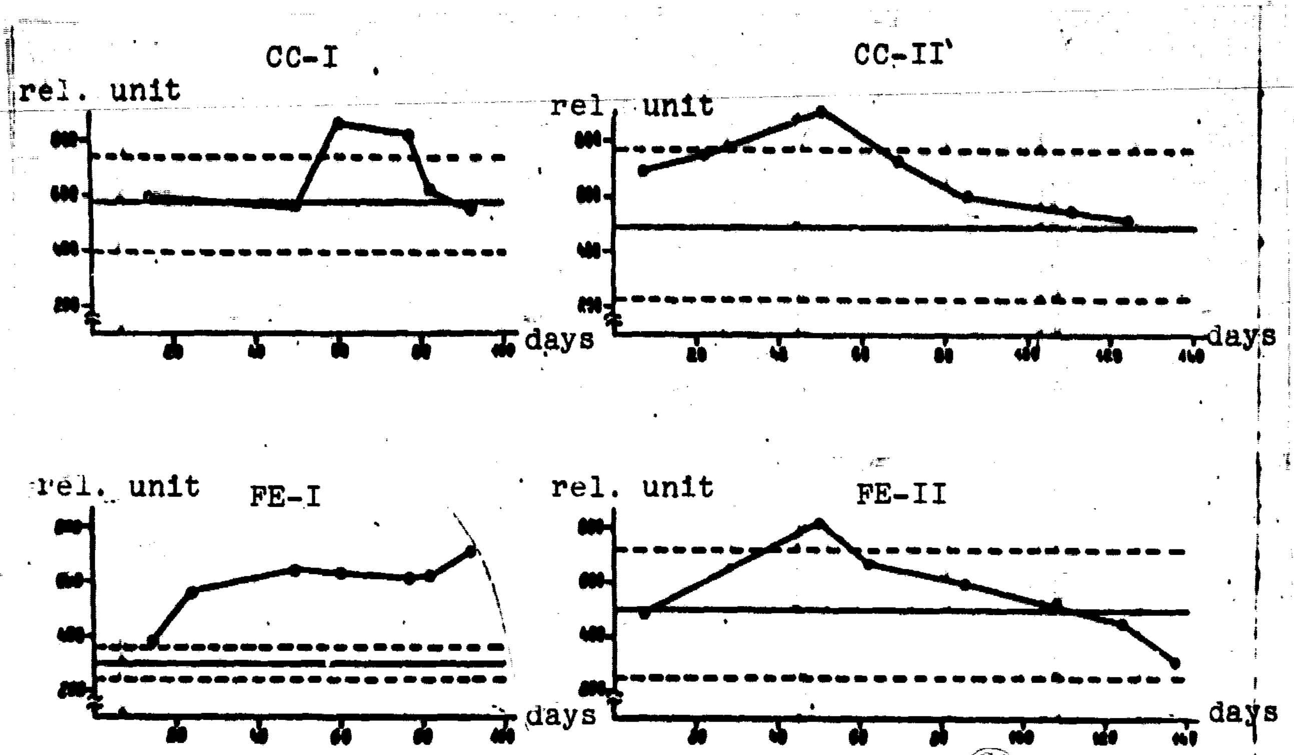

Figure 11. Dynamics of the index of minute blood filling of the vessels of the head in flight.
Symbols:
o-o-o - actual values of the index of minute blood filling of the vessels of the head in different periods of orbital flight;
____ - the average value of the index of minute blood filling of the vessels of the head in the preflight period;
\- - - - limits of variation of the index of minute blood filling of the vessels of the head in the preflight period;
CC-1 and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

The changes in indices of the diastole of the right ventricle (RV) of the heart also were characterized by an initial increase lasting for the first 2 months of the absolute and relative values of the diastole (by 24-38 and 11-12%), the period of filling (24-47%) and the phase of slow filling (38-70%). Later on, the values of these indices were decreased except for the absolute values of the diastoles and the filling period hardly differed from the preflight values. The phase of rapid filling for the entire flight was increased in the CC by 18-79% and in the FE by 22-85%. The absolute and relative values of the phase of isometric relaxation in the CC decreased and in the FE increased. /59

Thus, the changes in flight of the basic indices of the diastole of the right and left ventricles mainly had a uniform tendency.

Changes in the central and regional hemodynamics. Stroke volume (SV) on the fourth to seventh days of flight increased in 3 out of the four cosmonauts (Figure 8). Later on, as a rule, insignificant variations were observed primarily with insignificant increases in the average preflight values in the CC-1 and FE-II. Then, on day 82 an increase in SV was detected in the CC-I by 25%, and in the FE-II on day 119 with a decrease by 28%. In the FE-I, in distinction from the other cosmonauts, the SV was basically insignificantly decreased for the entire flight (by 2-15%). The minute volume circulation (MVC) hardly exceeded the average preflight values or did not differ from them in all of the cosmonauts (Figure 9). After flight, the SV and MVC in all four cosmonauts (except the MVC in the CC-I) was decreased and in expedition I was not reestablished during 11 days postflight. /60

The indices of pulse (PB) and minute blood filling (MB) of the head during the 96-day flight were increased in both cosmonauts, to a greater degree in the FE-II and did not decrease at the end of the flight. In the 140-day flight one also observed a marked increase in pulse and minute blood filling of the head, which, however beginning approximately on day 85 in the CC-II and day 110 in the FE-II did not differ or was even decreased in comparison with the preflight data, (Figures 10, 11). The asymmetry observed in pulse blood filling, more marked in crew I on the 49th to 77th days and in crew II on the 85th day, at the end of flight had decreased or even disappeared. The character of asymmetry in the CC-I was the same as the preflight; in the CC-II and FE-II, it had changed to the opposite and in the FE-I, the difference in blood filling of the vessels of the right and left hemispheres was apparent only during flight.

After flight, on day 3, crew I had pulse and minute blood filling increased and in FE-I there were no positive dynamics on day 11, but in the CC-I there was a tendency toward normalization. After the 140-day flight, on day 2, the pulse blood filling in both cosmonauts and the minute blood filling in the CC-II were, as a rule, considerably smaller than the preflight values. At the same time, in the FE-I the minute blood flowing to the right hardly changed and to the left it decreased markedly. Similar in direction but less marked, the tendency lasted for 4 days. Later on, on day 9, changes took on a different character: in the CC-II, blood filling of the vessels of the head increased by 55-65%, in the FE-II -- it decreased by 55-67%. /61

The pulse and minute blood filling of the crus in flight and on days 2-3 postflight was smaller than the preflight. In the cosmonauts of the two expeditions, one noted a weakly expressed tendency toward normalization of blood filling of the vessels of the crus in the second half of the flight.

The pulse and minute blood filling of the forearm during flight exceeded or did not differ from the preflight values and on days 2-3 postflight it was, as a rule, smaller than these values (except for the FE-I in whom these indices on days 3 and 11 were noticeably increased in comparison with the preflight value).

The arteriole and venous tone of the vessels of the head during flight in 3 of the 4 cosmonauts (except for the FE-II) was, as a rule, decreased and in a number of studies symptoms were detected of a significant dilation of the small vessels which showed up in the change in shape of the rheoencephalograms in such a way that the incisura shifted lower than the isoelectric line. In the FE-II, on different observation days, the tone of these vessels changed both increasing and decreasing. Postflight, the arteriole tonus also basically was decreased in 3 of the cosmonauts and increased in the FE-II. Moreover, the venous tone decreased only in the crew of the first expedition and had not recovered on day 11.

Changes in the arteriole and venous tone of the forearm and crus in different cosmonauts was individual and showed both as a decrease and an increase of the appropriate indices. However, in most cases, one noted a principle showing different directions of change of tone of the small vessels of the forearm; in 3 cosmonauts it decreased, /66
and in the FE-II it increased with a simultaneous increase in the tone of the small vessels of the crus in all the cosmonauts.

Thus, changes of the central and regional hemodynamics according to the data of rheographic studies showed the following:

-- at first (on days 4-7) with an increase in SV in 3 of the 4 cosmonuats, the tendencies of the MVC for the entire extent of the flight was toward an increase of preflight values and decrease of the volumes of circulation postflight;

-- an increase in pulse and minute blood filling of the vessels of the head which in the 140-day flight after 85-110 days, increased in the forearm values; then, after the 96-day flight the pulse and minute blood filling remained increased and after the 140-day decreased;

-- the appearance of asymmetry of blood filling of the cerebral vessels in crew 1 on days 49-77 and in crew 2 on day 85; this leveled off at the end of flight;

-- a decrease **in-flight** and postflight of blood filling of the vessels of the crus with simultaneous increase or absence of change of blood filling of the forearm (only in-flight);

-- a decrease in arteriole and venous tone of the vessels of the head in 3 cosmonauts in-flight and postflight;

-- different types of change in the tone of the arterioles and veins of the forearm and crus, whose changes had an individual character in different crew members.

The changes of the central and regional hemodynamics in conditions of space flight can be due to a number of factors the most important of which is redistribution of blood and functional loads of different regions of the body.

Venous pressure, determined by an indirect method on a phlebogram of the jugular vein while applying negative pressure to the lower part of the body, during the 140-day flight first increased by 1.5-2 times and by day 85 of the flight had normalized and then again increased. In the 96-day flight, the value of venous pressure was increased to an even greater degree and did not have a tendency toward a decrease (Figure 12). /67

According to the data of plethysmographic studies (V. A. Deytyarev and coauthors), the venous pressure in the lower extremities in-flight (was studied only in the MC-II) in the FE-II on day 130 amounted to approximately 8 mm Hg and in the FE-II on day 125, about 6 mm Hg. The time for the plethysmographic curve to reach the plateau and the maximim increase in the crus was increased which, apparently, caused a decrease in the tonus veins and an increase in their expandability. The volume rate of blood flow in the crus increased.

At the present time it is assumed that the main factor which determines the qualitative peculiarity and specifics of physiological shifts in the organism in conditions of spaceflight is weightlessness [8,9]. The main length in the mechanism of effect of weightlessness is, apparently, a decrease in the functional load on a number of systems due to the absence of weight and involving this the mechanical stress on the structure of the body [8,9,10].

In weightlessness, redistribution of the fluid media of the organism occurs in a cranial direction, and lasts continuously for the entire extent of the flight. The shift in the center of mass of the body discovered during studies on the Skylab program is evidence of this [11], and also the tendency toward an increase in cardiac output, venous pressure and the indices of pulse blood filling of the head, recorded during flight according to the Salyut program. This redistribution of fluids, probably, is the cause of a number of mechanisms which result in the change of physiological functions (Table 4).

In a much later period in weightlessness, as a result of constant physical lack of load on the organisms (particularly with inadequate physical exercises) and the assumed decrease in posture-tonic function of the muscles (no necessity for counteracting the force of gravitation), the muscle system to a larger or smaller degree becomes out of condition. As a result, one can decrease the activity of the intramuscular peripheral heart, which shifts the blood from the arteries

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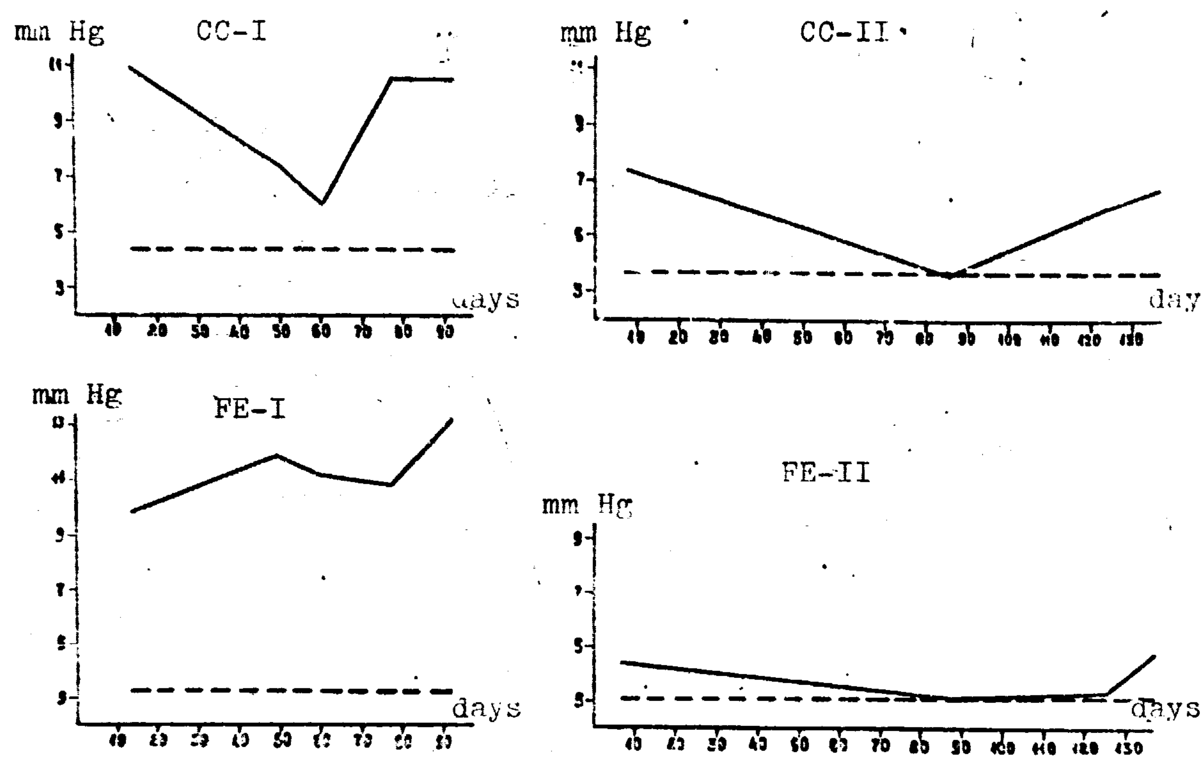

Figure 12. Dynamics of the index of venous pressure in-flight.
Symbols:
\- - - - - - average value of the index in the preflight period;
_______ - value of the index in-flight;
CC-I and CC-II - the commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

through the capillaries of the skeletal muscles through the veins; this makes the work of the heart easier and facilitates recovery of the venous blood to the right heart [21]. The decrease in intraorgan pumping functions of the skeletal muscles also can cause the development of venous congestion and an increase in venous pressure. /69

TABLE 4

A GENERAL DIAGRAM OF THE MECHANISMS OF CHANGE IN THE PHYSIOLOGICAL FUNCTIONS CAUSED BY A SHIFT IN FLUIDS IN A CRANIAL DIRECTION

-- an increase in transmural absorption of the tissue fluid;

-- a decrease in tissue pressure in the field of the lower extremities (a decrease in the volume of the lower extremities);

-- an increase in transmural pressure and filtration in the capillaries of the upper part of the body (edema of the tissue above the heart level);

-- increase in venous recovery expansion of the central veins in the auricle and an increase in cardiac output;

-- an increase in the indices of pulse blood filling of the head and jugular veins;

-- an increase in venous pressure (in-flight, pressure recorded in the jugular veins), which was established at the level of central venous or right-arterial pressure [11];

-- a decrease in the gradient of pressure in the venous system;

-- an increase in the role of the active diastole and hemodynamics;

-- development of a phase syndrome of load by volume;

-- an increase in pressure in the cardiopulmonary region and retardation of vasomotor centers [12];

-- an increase in the tone of the vagus and engagement of the discharge reflexes [13,14,15] with the receptors of the pulmonary vessels, which limit inflow of blood to the heart and decrease tone of the vessels of the greater circle (tendency to decrease of arterial pressure and peripheral resistance);

-- removal of part of the fluid according to the Henry-Gauer mechanism (loss of weight of certain electrolytes) and an increase in the blood-storing organs as a result of stimulation of the receptors of the auricle and the pulmonary vessels [13,17,18,19], which partially compensates for the manifestation of shifts (a decrease in edema of the face, perception of a rush of blood, etc.);

-- stabilization of a new functional level of blood circulation due to engagement of compensatory mechanisms with the carotid sinus [12,20].

TABLE 5

MECHANISMS OF CHANGE OF CERTAIN FUNCTIONS OF THE ORGANISM IN WEIGHTLESSNESS

1. Perception of congestion of blood in the head:

- shift in fluids in the cranial direction.

2. Edema of the tissue of the body below the level of the heart:

- increase in trasmural pressure in the capillaries located above the level of the heart.

3. Decrease in weight:

- removal of part of the fluid from the organism;
- partial loss of muscle mass;
- increased physical activity and emotional stress;
- limitation of food intake.

4. Decrease in the volume of the lower extremities:

- shift of fluid in the cranial direction;
- increase in transmural absorption of tissue fluid and a decrease in tissue pressure;
- a decrease in muscle tone and certain loss of muscle mass.

5. Tendency toward an increase in cardiac output:

- shift in fluid in a cranial direction;
- increase in venous recovery.

6. Increase in venous pressure and blood filling of the jugular veins:

- shift of fluid in a cranial direction;
- development of a general venous congestion as a result of decrease in pressure gradient in the vein system and, possibly, as a result of decrease in activity of intramuscular peripheral blood vessels;
- tendency toward an increase in cardial output.

7. Increase in expandability of the veins of the crus:

- decrease in muscle tone;
- decrease in tissue pressure.

8. Restructuring of the phase structure of the cardiac cycle (increase in power and effect of duration of the cardiac contraction, increase in the phase of rapid filling, increase in the hemodynamic ineffective isometric phases and a decrease in the rest time of the cardiac muscle):

- load on the heart by volume, increase in the role of the intake function of the heart by the active diastole in the hemodynamics as a result of the decrease in the pressure gradient in the venous system.

2.1.3. Results of Studies with Application of Negative Pressure to the Lower Half of the Body and their Discussion. /72

All of the examinations made both preflight and in-flight were accompanied not only by the development of symptoms of collapse but also unfavorable subjective perceptions, complaints of worsening in feelings of well being. During an analysis of the reactions of the cardiovascular system to negative pressure in the samples in the preflight period attention was given to several more marked changes in a number of indices in the period directly preceding the launch, observed in three of the four cosmonauts (MC-I and II) (except for the CC-II), which apparently, was due to a certain amount of fatigue which occurred during the intense preparation for launch. Nevertheless, the main criterion in evaluating the transferability of flight tests was the degree of expression of the reaction of the cardiovascular system relative to maximum manifestation of reactions in the ground tests.

Frequency of cardiac contraction in three cosmonauts (except for the CC-I) when creating negative pressure during flight increased to a greater degree than in the preflight tests whereas the increase in reaction of FCC occurred on a background of a gradual increase from test to test of the chronotropic function of the heart in its initial state (Figure 1). Whereas the preflight increase of FCC in response to negative pressure in these cosmonauts on the average amounted to 15.6%, in-flight it increased to 21.6%. The FE-I had an increase in FCC reaction observed on days 14, 60 and 92 of the flight and on days 49 and 77 it corresponded to the maximum ground value. In crew members of the MC-II, a more marked reaction of the FCC or even maximum preflight was traced in all flight observations except studies made on day 7. In the CC-I the FCC reaction, on the other hand, in the second half of the flight decreased and approximately corresponded to the maximum terrestrial reaction only in the test on day 14. /74

Indices of arterial pressure as a whole changed moderately. The minimum AP in the flight tests during LBNP (Figure 2) in the CC-I decreased on days 14 and 49, respectively, to 11 and 9 mm Hg. In this same crew member in the preflight period, as a rule, one observed an increase in the index and only in the test just before launch did one note a short term decrease in the index (9 mm Hg). In the FE-I, both in the preflight test and in the test in the second half of the flight, one noted a tendency toward a small decrease in the diastolic AP. In the members of the MC-II, in distinction from the MC-I, with negative pressure, one observed only singular cases of an insignificant decrease in minimum AP, and a constant reaction was apparent in the form of an increase of the index (maximum at 8 mm Hg). The mean dynamic AP in the flight test changed approximately unidirectionally with minimum AP but with a large degree of variation both toward a decrease and toward an increase in the values (Figure 3). A particularly large

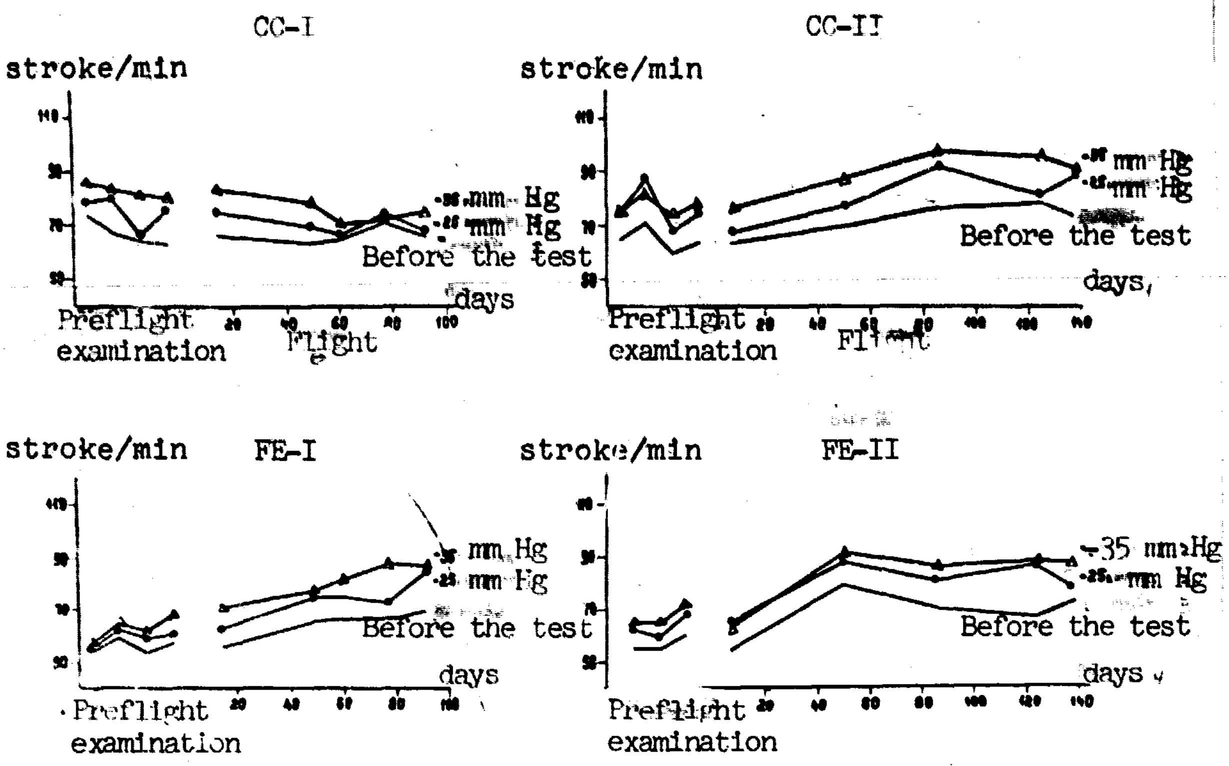

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Figure 1. The dynamics of frequency of cardiac contractions when carrying out tests with the application of negative pressure to the lower of the body in-flight.
Symbols:
______ – mean value of the frequency of cardiac contractions before the test;
-o-o-o – maximum value of the frequency of cardiac contractions during negative pressure -25 mm Hg;
\- - - – maximum value of the frequency of cardiac contractions during negative pressure -35 mm Hg;
CC-I and CC-II – commanders of the first and second main crews;
FE-I and FE-II – flight engineers of the first and second main crews.

spread in the values of mean AP in response to negative pressure /74
occurred in the FE-I. In the CC-I, the reaction occurred according to the type of decrease in the index, then in three tests out of five (on days 14, 60 and 92) with a large degree of expression, in comparison with the preflight (decrease at 14-17 mm Hg, preflight maximum at 7 mm Hg). The lateral and terminal systolic AP in members of the MC-I, in all flight tests decreased and in tests on day 14 the relative decrease of lateral in the FE-I and terminal in the CC-I was more marked than the preflight (Figures 4,5). Lateral AP in the CC-II in the last preflight and in all the flight tests during negative pressure, on the other hand, increased (at 2-10 mm Hg). During decompression, in accordance with variations of minimum and lateral AP, the changes of pulse AP also in the same test, in a number of cases, acquired positive and negative values in relation to the initial level (Figure 6). Pulse AP in its dynamics basically had a tendency toward

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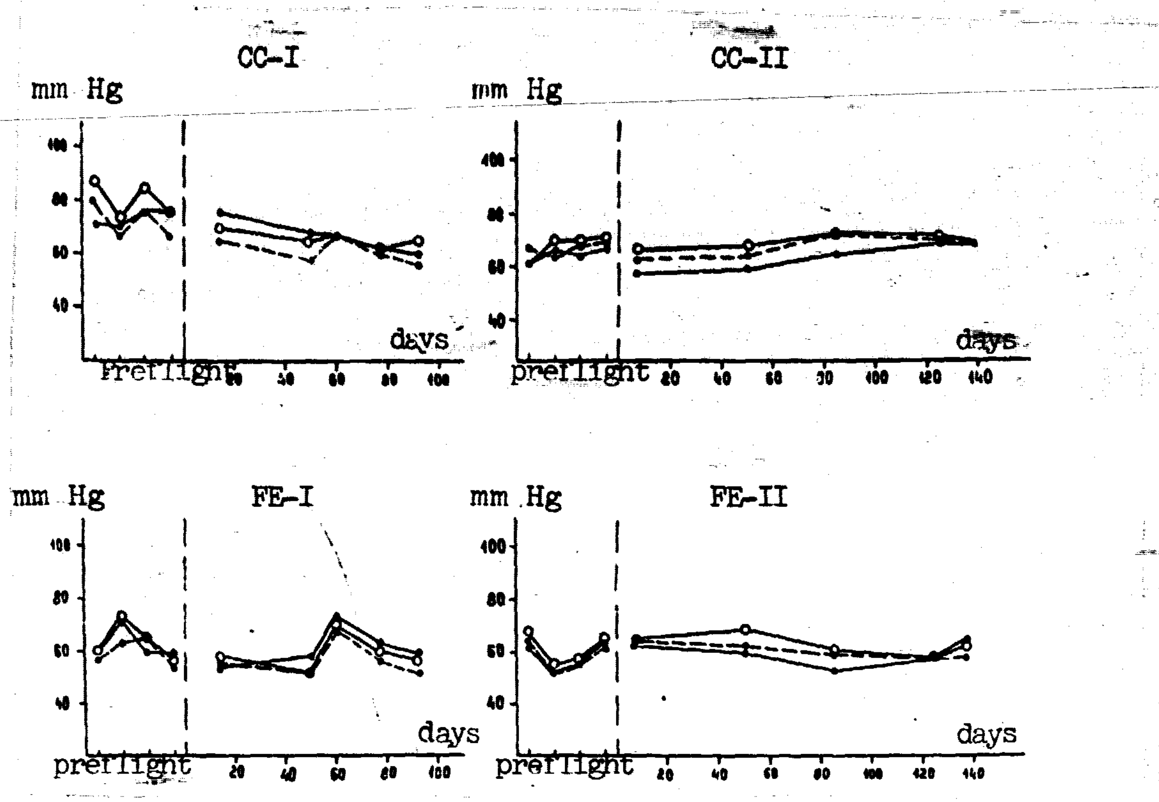

Figure 2. The dynamics of minimum arterial pressure in-flight when conducting tests with application of negative pressure to the lower part of the body.
Symbols:
_____ - mean values of the index before the test;
o-o-o- - maximum values of the index with negative pressure -35 mm Hg in different periods of orbital flight;
- - - - minimum values of the index during negative pressure -35 mm Hg in different periods of orbital flight;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

a decrease which was more marked than in the preflight tests. An exception was the sharper decrease in pulse AP (in the CC-I in the test on day 95 and FE-I in the test on the day 14) while retaining, however, an adequate level of the absolute values (30-35 mm Hg). Besides the ordinary reaction of decrease, small increases in the index occurred in the final minutes of negative pressure (in the FE-I on day 49, in the CC-II on days 50 and 85, in the FE-II on day 137). /80

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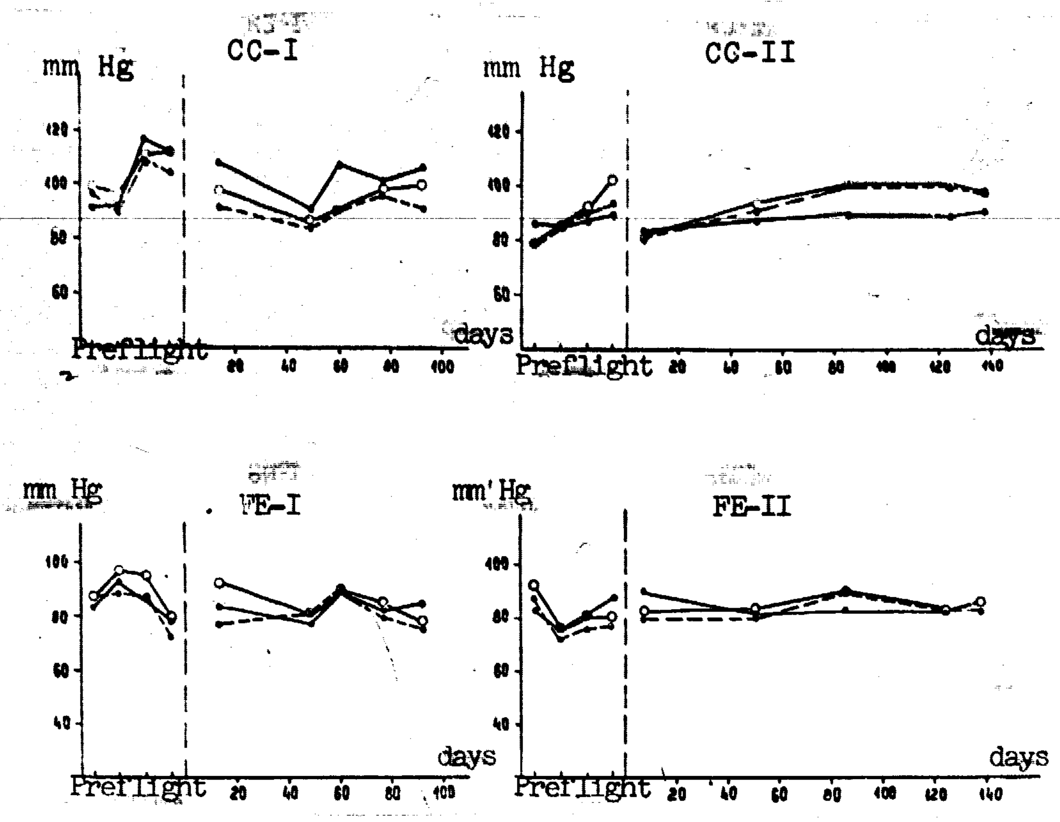

Figure 3. Dynamics of the mean arterial pressure in-flight with conduct of tests with application of negative pressure on the lower part of the body.
Symbols:
_____ - mean values of the index before the test;
-o-o- - maximum values of the index with negative pressure -35 mm Hg in different periods of orbital flight;
- - - - minimum values of the index during negative pressure -35 mm Hg in different periods of orbital flight;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

Changes in the phase indices in the systole of the left ventricle (Figures 7-9) in its totality indicated the development during negative pressure of symptoms of a phase syndrome of functional hypodynamics (according to V. L. Karpman). This was manifested, as a rule, in shortening of the phase of isometric contraction and lengthening of the period of ejection of blood by the left ventricle due to which the ratio IC/PE increased. The changes indicated in the flight tests were more marked in the CC-I on day 14, in the FE-I on day 77, in the CC-II on days 7, 85 and 137 and in the FE-II on day 137 of the flight. In /80

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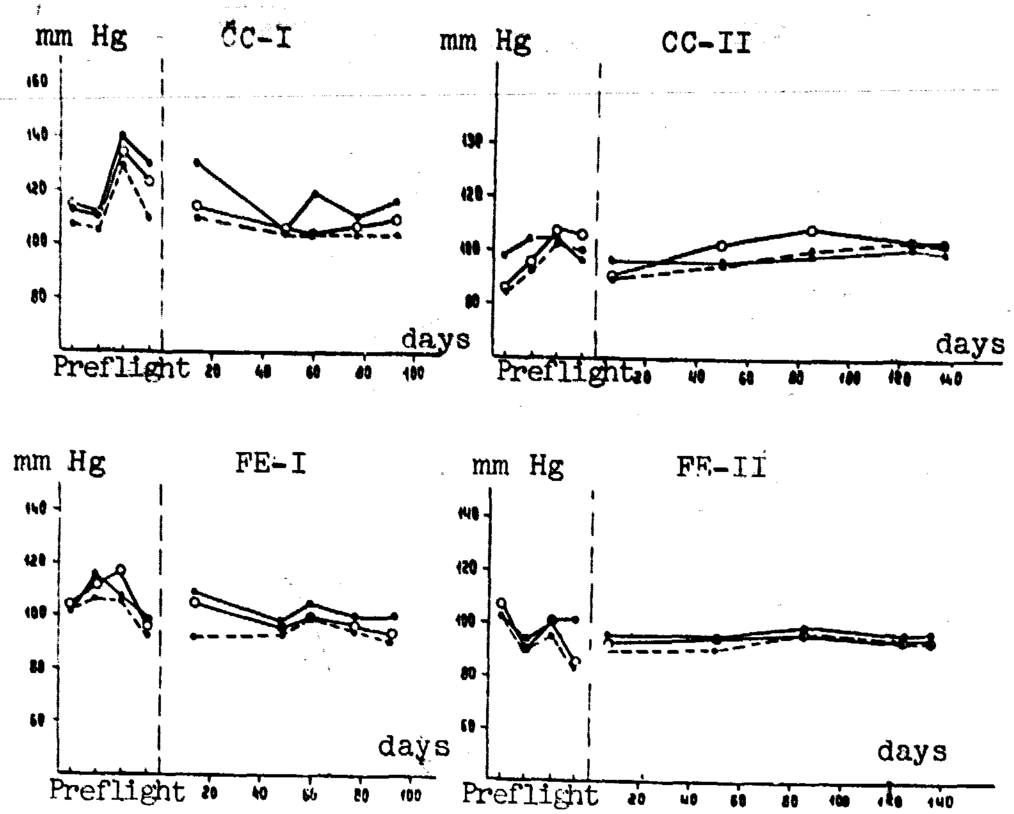

Figure 4. The dynamics of lateral systolic arterial pressure in-flight when conducting tests with application of negative pressure on the lower part of the body.
Symbols:
______ - mean values of the index before the test;
-o-o- - maximum values of the index with negative pressure -35 mm Hg in different periods of orbital flight;
- - - - minimum values of the index with negative pressure -35 mm Hg in different periods of orbital flight;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

the FE-I, a decrease in value of PE during negative pressure had a progressive character from test to test (from 0.22 s in the last preflight test to 0.17 in the test on day 92). In the CC-I, beginning on day 49 of the flight, the changes in phase indices were more marked than in the preflight period. Lengthening of the IC phase in the CC-II, in all flight samples was greater than on Earth. On the average, the ratio of IC/PE preflight increased by 31.1% and in-flight by 60.1%. It is surprising that in the FE-II, in the tests on days 7 and 124 /80

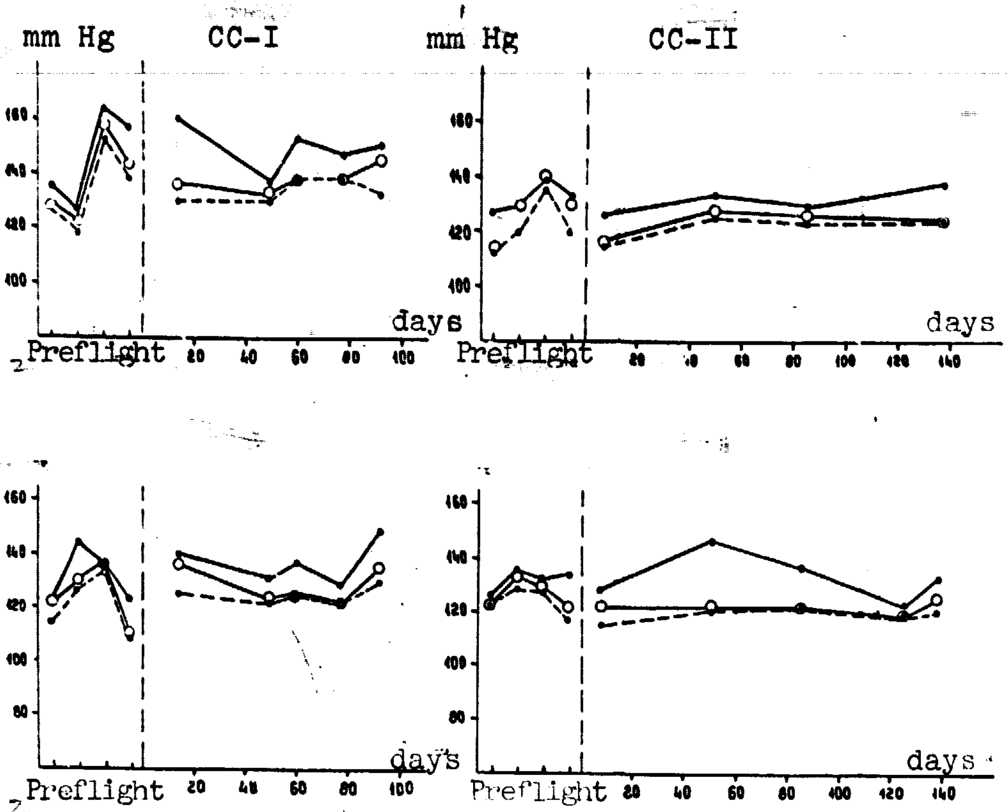

Figure 5. The dynamics of terminal systolic arterial pressure in-flight when conducting tests with application of negative pressure on the lower part of the body.
Symbols:
_____ - mean values of the index before the tests;
o-o-o - maximum values of the index with negative pressure -35 mm Hg in different periods of orbital flight;
- - - - minimum values of the index with negative pressure -35 mm Hg in different periods of orbital flight;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

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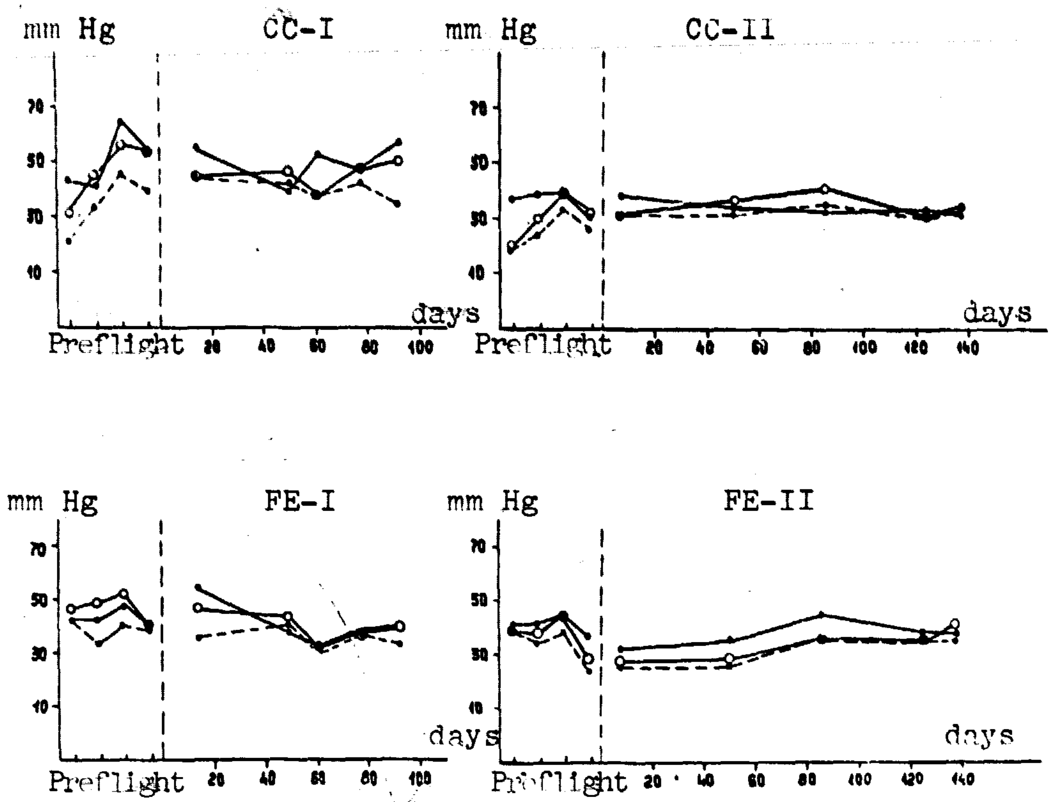

Figure 6. The dynamics of pulse arterial pressure in-flight when conducting the test with application of negative pressure on the lower part of the body.
Symbols:
______ - mean values of the index before the test;
o-o-o - maximum values of the index with negative pressure -35 mm Hg in different periods of orbital flight;
- - - - minimum values of the index with negative pressure -35 mm Hg in different periods of orbital flight;
CC-I and CC-II - commanders of the first and second main crews;
FE-1 and FE-II - flight engineers of the first and second main crews.

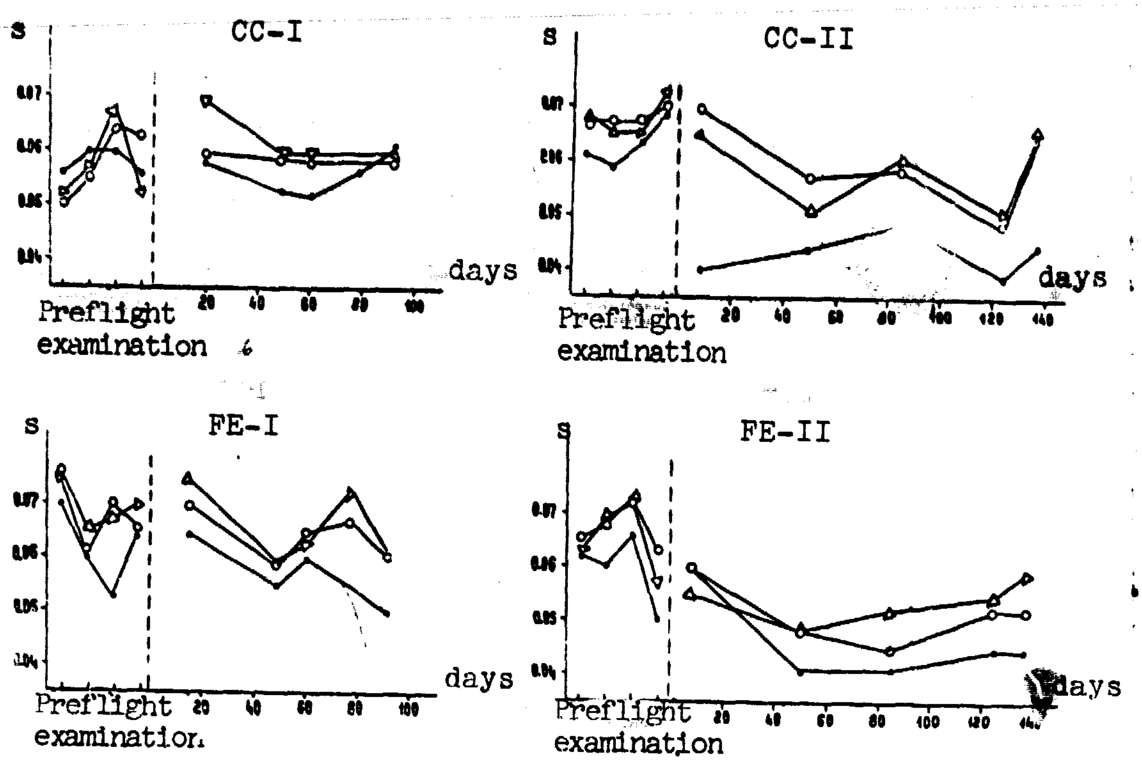

Figure 7. Dynamics of the duration of a phase of isometric contraction of the left ventricle when conducting a test with application of negative pressure on the lower part of the body in-flight.
Symbols:
_____ - value of the index before the test;
o-o-o - mean value of the indices with negative pressure -25 mm mercury column;
-Δ-Δ- - mean values of the indices during negative pressure -35 mm Hg;
CC-I and CC-II - commanders of the first and second main crews of the orbital Salyut-6 and Soyuz complex;
FE-I and FE-II - flight engineers of the first and second crews of the orbital Salyut-6 and Soyuz complex.

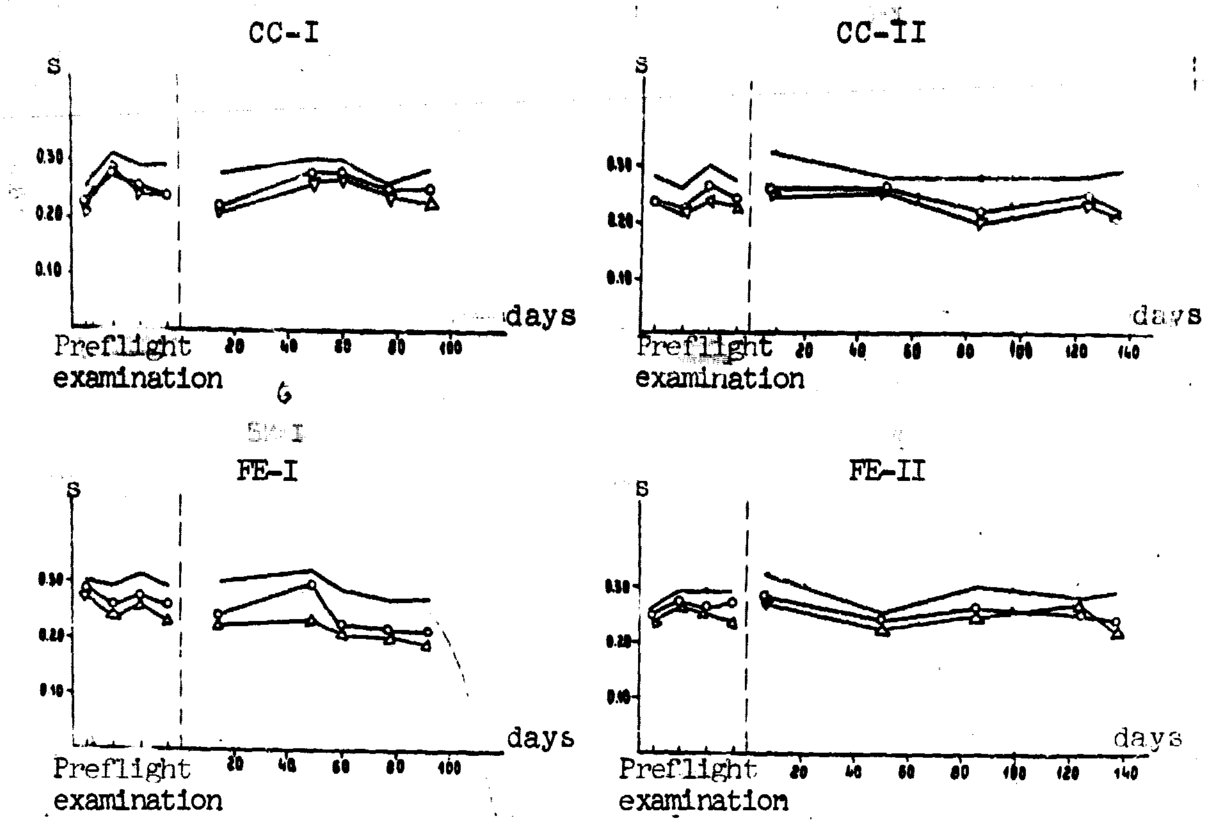

Figure 8. Dynamics of the duration of the period of ejection of the left ventricle when conducting a test with application of negative pressure on the lower part of the body in-flight. Symbols:

_____ - value of the indices before the test;
o-o-o - mean values of the indices with negative pressure -25 mm Hg;
Δ-Δ-Δ - mean values of the indices with negative pressure -35 Hg;
CC-I and CC-II - commanders of the first and second main crews of the orbital Salyut-6 and Soyuz complex;
FE-I and FE-II - flight engineers of the first and second main crews of the orbital Salyut-6 - Soyuz complex.

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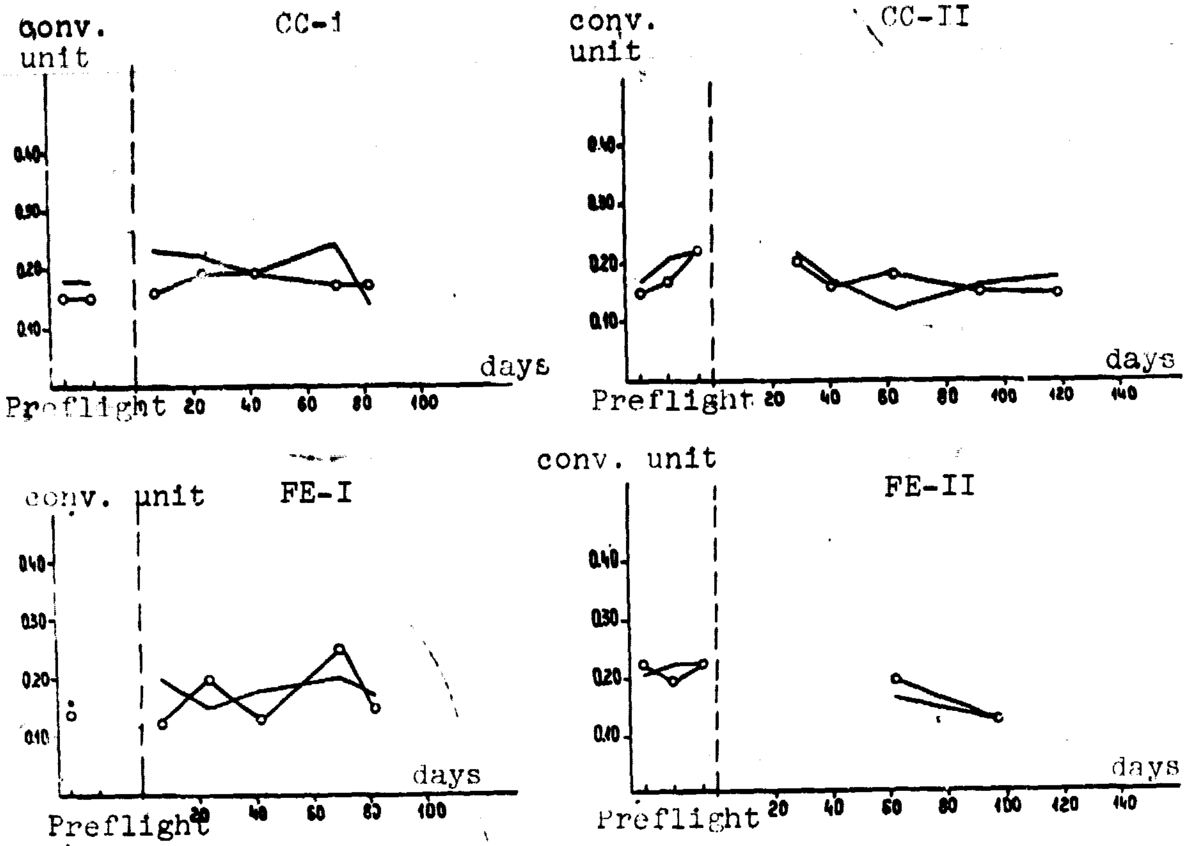

Figure 9. Dynamics of the ratio of isometric contraction through the period of ejection of the left ventricle when conducting a test with application of negative pressure to the lower part of the body in flight.

Symbols:

_____ - value of the indices before the test;

o-o-o - mean values of the indices with negative pressure -25 mm Hg;

- - - - mean values of the indices with negative pressure -35 mm Hg;

CC-I and CC-II - commanders of the first and second main crews;

FE-I and FE-II - flight engineers of the first and second main crews.

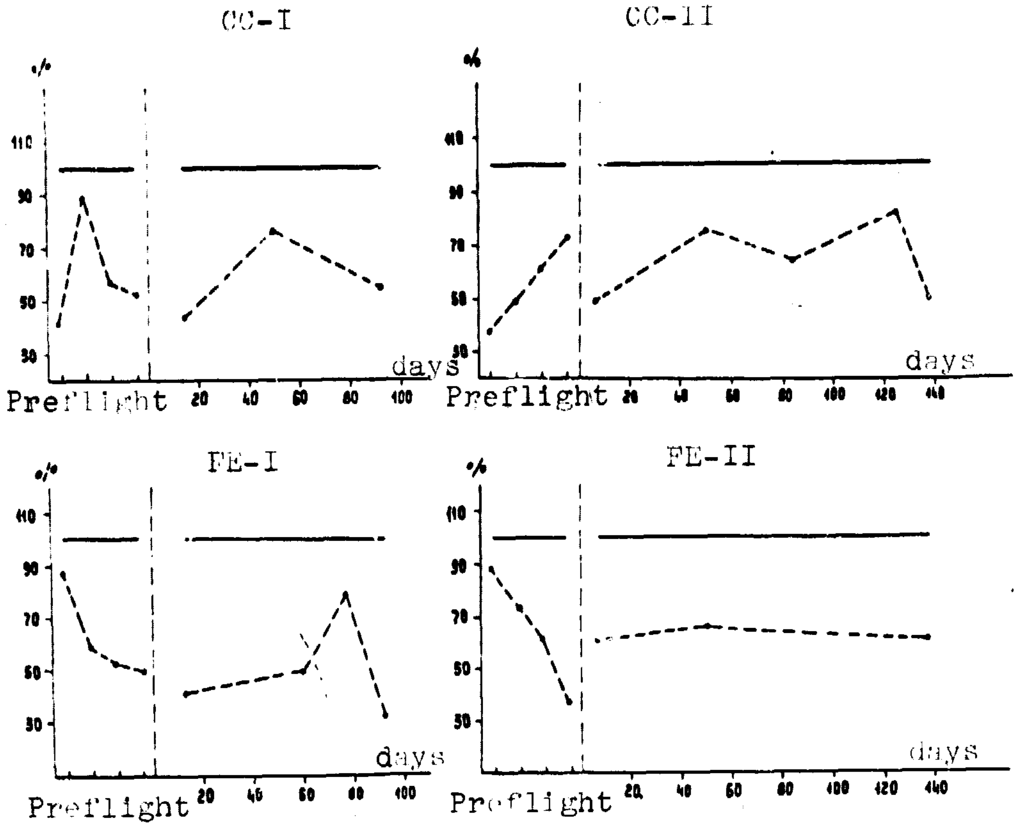

Figure 10. Dynamics of stroke volume of the heart in-flight when conducting tests with application of negative pressure on the lower part of the body.

Symbols:

_____ - mean value of stroke volume of the heart before the test;

- - - - minimum values of the index in percentage points in relation to the value recorded before the test, at negative pressure -35 mm Hg in different periods of orbital flight;

CC-I and CC-II - commanders of the first and second main crews;

FE-I and FE-II - flight engineers of the first and second main crews.

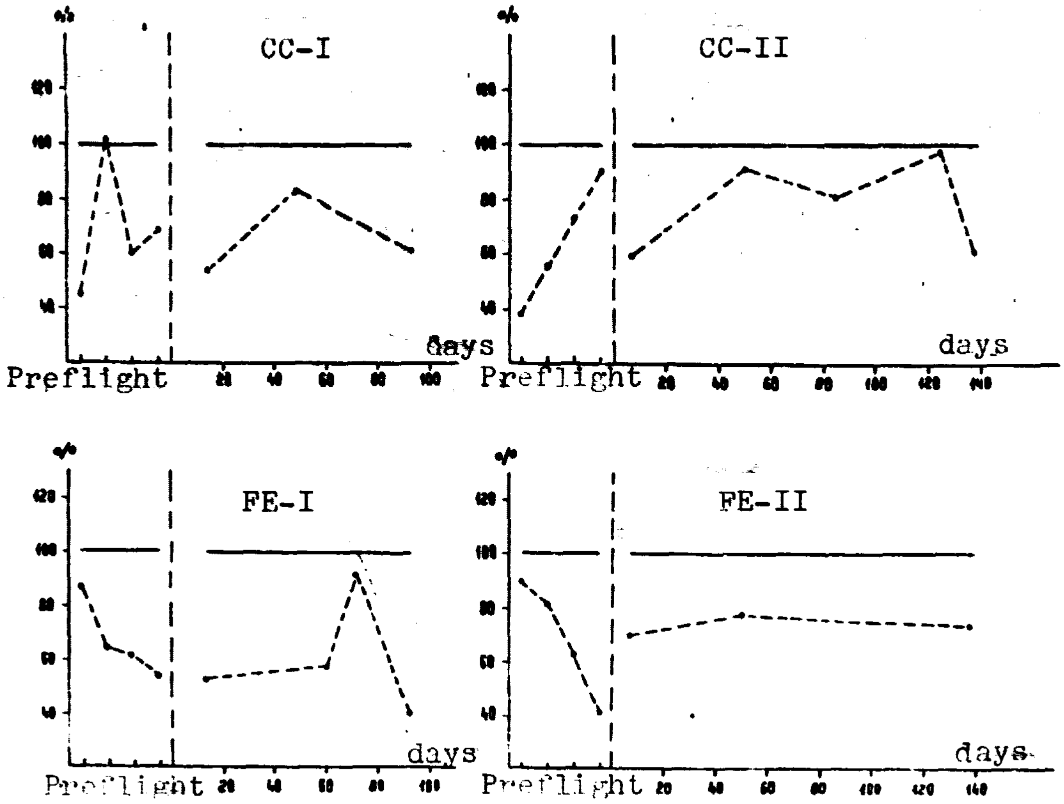

Figure 11. Dynamics of minute volume of blood circulation in-flight when conducting a test with application of negative pressure on the lower part of the body.
Symbols:
_____ - mean value of minute volume of blood circulation before the test;
- - - - minimum values of the index in percentage points in relation to the value recorded before the test with negative pressure -35 mm Hg in different periods of orbital flight;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

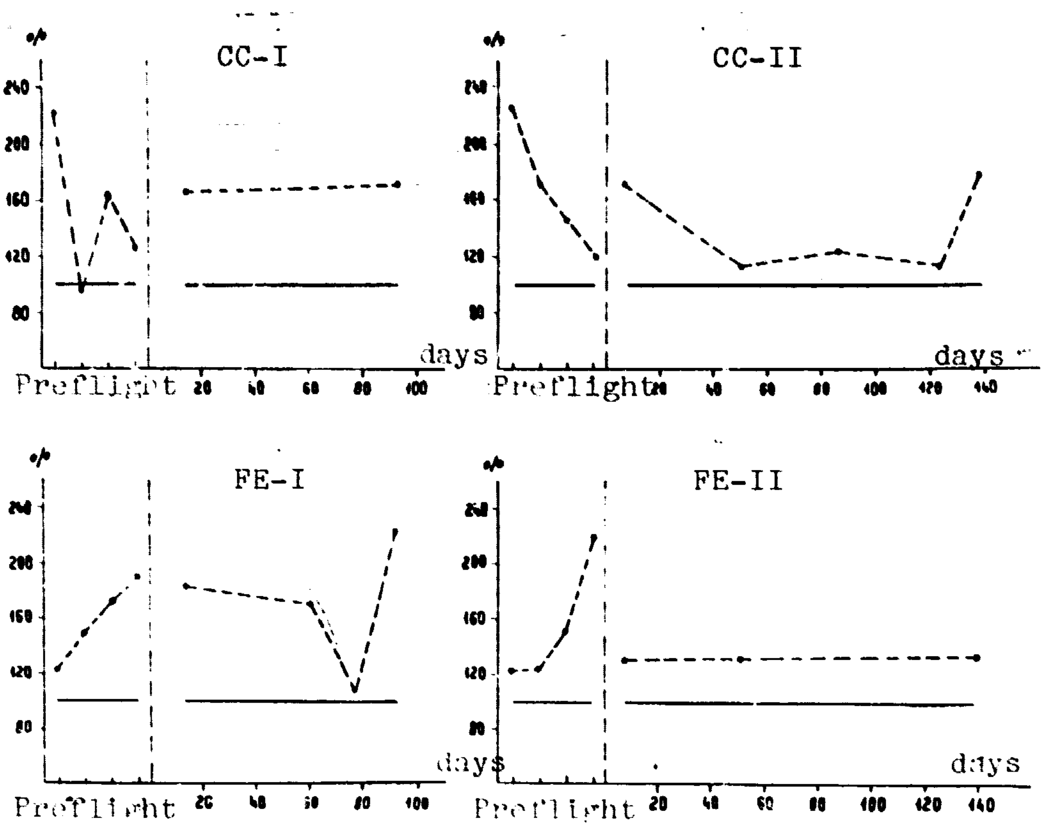

Figure 12. Dynamics of specific peripheral resistance (actual) in-flight when conducting a test with application of negative pressure on the lower part of the body.
Symbols:
___ - mean value of the index before the test;
- - - - maximum values of the index in percentage points in relation to value recorded before the test at negative pressure -35 mm Hg in different periods of orbital flight;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

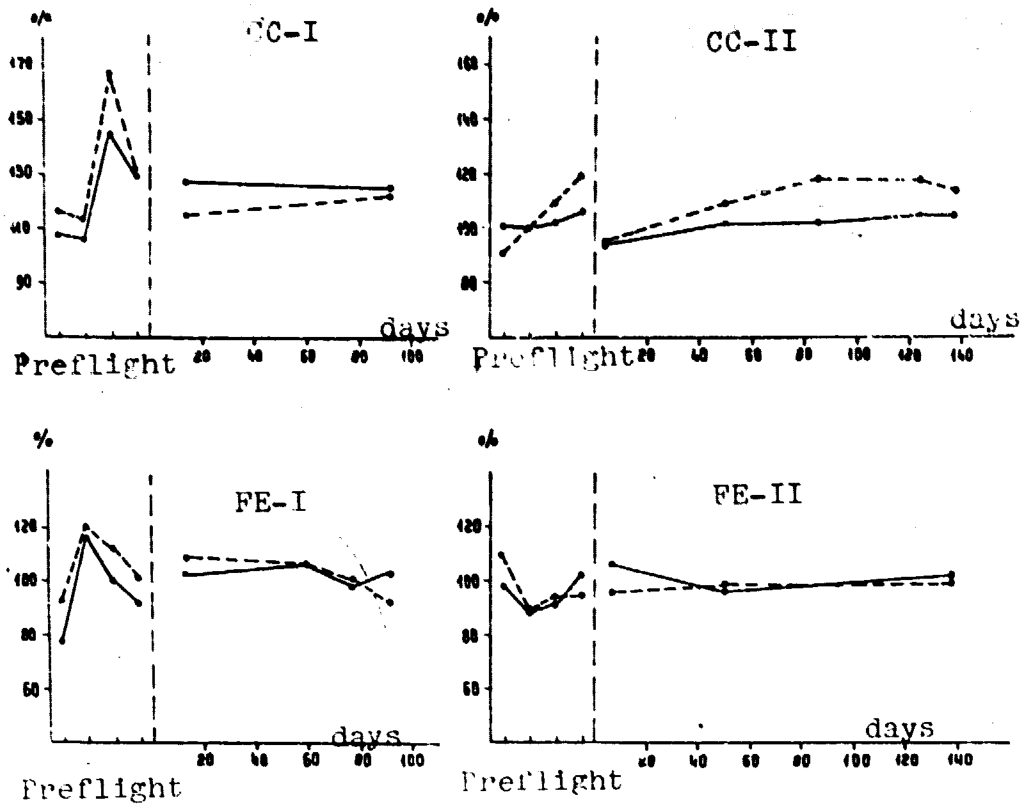

Figure 13. Dynamics of the ratio of specific peripheral resistance of actual required to specific peripheral resistance in-flight when conducting a test with application of negative pressure on the lower part of the body.
Symbols:
_____ - mean values of the index before the tests;
\- - - - maximum values of the index at negative pressure -35 mm Hg in different periods of orbital flight;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

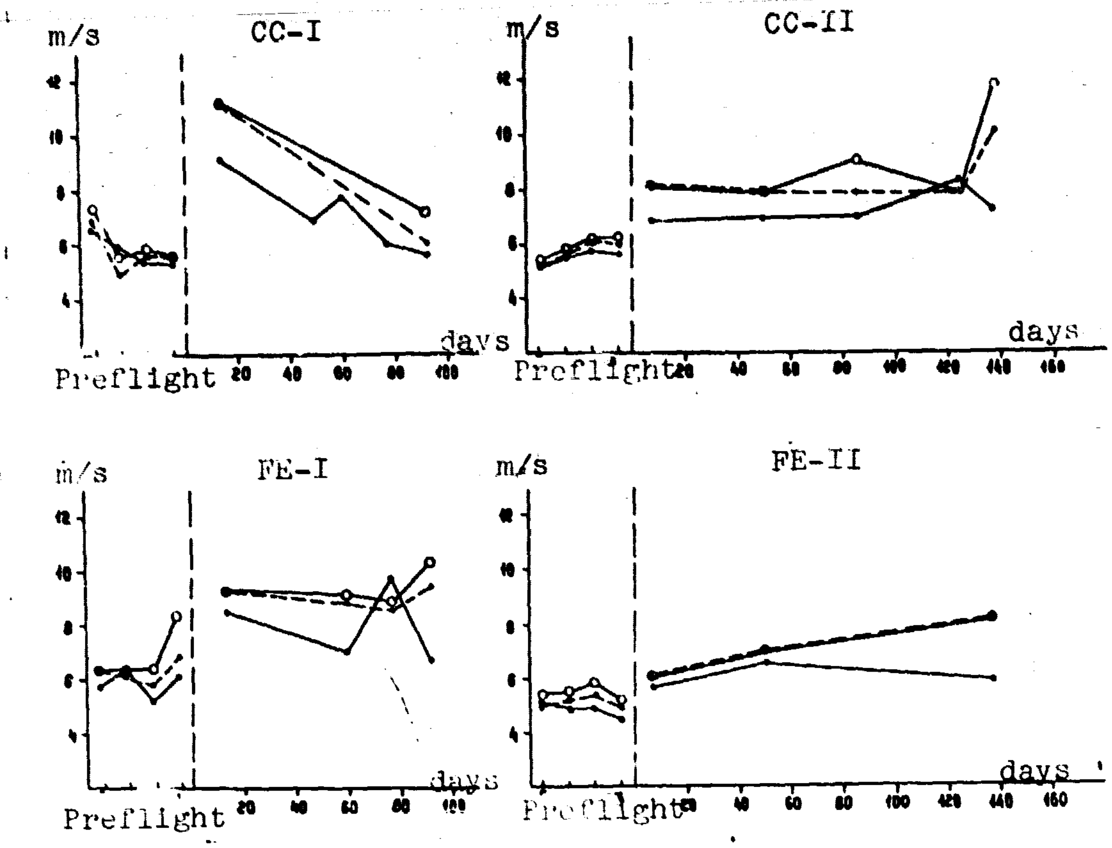

Figure 14. Dynamics of the rate of migration of the pulse wave along the aorta in-flight when conducting tests with application of negative pressure on the lower part of the body.
Symbols:
_____ - mean values of the rate of migration of the pulse wave along the aorta before the test;
o-o-o - maximum values of the index with negative pressure -35 mm Hg in different periods of orbital flight;
- - - - minimum values of the index with negative pressure -35 mm Hg in different periods of orbital flight;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

either in general no changes in the IC phase were noted or it was shortened. /80

Decrease in value of cardiac output (determined according to the Braemser-Ranke method) with creation of LBNP (Figures 10, 11), in the members of MC-I in all of the tests except on day 92, the results were approximately the same as in preflight examinations (in-flight, on the average, 37.6%, preflight 35.2%). In the test on day 92, the decrease in minute volume of blood circulation in both the cosmomauts of this crew was more marked and amounted to 39-61%. In members of the second crew during flight none of the tests for the effect of LBNP caused a more marked decrease in the volume of hemocirculation than in the preflight period. Moreover, in the FE-II with negative pressure -25 mm Hg in the test on day 124 a low value of MVC was fixed due to /86
insignificant changes in SV on a background of negative tachycardia. In accordance with a decrease in MVC, an increase was determined of specific peripheral vascular resistance (Figures 12, 13), whose negative increase however did not exceed in any of the flight tests (except the FE-I on day 92) those of the ground examinations. At this time, the tone of the main arteries according to the data of the rate of propagation of the pulse wave along the aorta (Figure 14) in three cosmonauts (except for FE-II) increased under the effect of LBNP in-flight to a large degree. Whereas preflight this index increased by a maximum of 11-27%, in-flight in certain tests it increased 36-76%. More significant than in the preflight tests an increase of RPPWa was detected in the CC-I and CC-II in the majority of flight tests, and in the FE-I and FE-II only at the end of flight (respectively, on days 92 and 137). In two cases (in the FE-I on day 77 and the CC-II on day 124) a decrease in this index was fixed.

An evaluation of individual reaction on the effect of LBNP showed that during flight, the relative decrease in transferability in the CC-I was observed during the first test on day 14. The characteristic peculiarity of this test was a decrease in all values of AP exceeding the preflight (Min AP -- 11, Av AP -- 16, Lt AP -- 20, Tr AP -- 30 mm Hg), increase of RPPWa by 2.1 m/s to 11.23 m/s. The volumes of hemocirculation then decreased: SV from 103 to 43 mℓ, MVC from 5.8 to 3.1 ℓ/min, maximally decreased PE time and IC phase increased (respectively to 0.21 and 0.075 s). With subsequent tests on the CC-I, one noted a sharp tendency toward a decrease in the reaction of the cardiovascular system to the effect of LBNP; however, the increase in RPPWa under negative pressure remained large (1.5-2.4 m/s). On day 92, in spite of the noticeable decrease in the value of AP (except for Min AP, at 16-19 mm Hg), the volumes of hemocirculation decreased only to 81 mℓ /[illegible]
and 6.0 ℓ/m.

In the FE-I on day 14 of the flight also one observed a reaction to the effect of LBNP more marked in comparison with preflight data. The increase in FCC was 15 beats per minute (preflight 5 beats/min), the AP values: Lt AP, Tr AP and PAP decreased to 17, 13 and 20 mm Hg, respectively; SV -- to 43 mℓ, MVC -- to 3.1 ℓ/min. The FE was shortened to 0.21 seconds. In subsequent tests made in-flight, in the FE-I, one observed a progressive increase in FCC, RPPWa, shortening of the

PE and lengthening of IC phase, as well as a decrease in the volumes of hemocirculation. At the same time, the changes in AP had a relatively moderat. character. An exception was the test on day 77 when the transferability of this test was evaluated by the cosmonauts subjectively as being worse than all the preceding. Then, on a background of relatively small FCC reactions, the AP and volumes of hemocirculation making up the shifts in IC and PE phases were significant (shortening of the PE to 0.19 s). However, the maximum changes of almost all of the indices studied in the blood circulation system accompanied the test on day 92 when the FCC increased to 87 beat/min, all of the values of AP decreased at 6-23 mm Hg, the stroke and minute volumes of hemocirculation dropped, respectively, to 3 mℓ and 2.6 ℓ/min, the period of ejections was reduced to 0.17 s, the ratio of IC/PE increased with 0.18 to 0.32 and the increase in RPPWa was 3.6 m/s.

In the CC-II, as was noted above, the increase in FCC beginning on day 85 of flight noticeably exceeded the preflight data both in the initial state and under LBNP. On days 85, 124 and 137, the absolute values of FCC under negative pressure reached respectively, 98, 96 and 91 beats/min with a maximum preflight value of 83 beat/min. These changes were very significant among all of the changes of FCC in the group of cosmonauts analyzed. Another characteristic feature of the reaction of the blood circulatory system of the cosmonauts was really significant shifts in the index of the phase structure of the systole of the left ventricle of the heart which was apparent in the development of a phase syndrome of functional hypodynamics in the tests on days 7, 85 and 137 (lengthening of the IC phase by 0.025-0.029 seconds, shortening of the PE by 0.08-0.085 seconds, and increase in the IC/PE ratio by 0.13-0.146). However, one should note that these changes qualitatively differed from each other and were accompanied by changes, differing in degree, of the other indices of hemodynamics. For instance, on day 7 of the flight, the initial state before negative pressure was the presence of a phase syndrome of load with volume (IC amounted to 0.04 s, PE -- 0.320 s, preflight these indices, respectively, equaled 0.059-0.069 s and 0.263-0.295 s), and the absolute value which these indices reached with negative pressure in spite of the significant relative "deficit" corresponded to the preflight. This test was accompanied by an average increase in FCC and changes of AP. At the same time, the values of MVC decreased lower than the minimum preflight value. On days 85 and 137, in the initial state, the PE time hardly differed at all from the preflight and the absolute values of PE under LBNP were significantly lower than the preflight, amounting, respectively, to 0.191 and 0.206 s (preflight -- 0.225-0.240 s). Then, on day 85, a very high degree of tachycardia was noted the value of the lateral systole AP in distinction from the preflight dynamics, increased and on day 137 significant decrease occurred in the value of stroke volume of the blood (less than 48 mℓ) with simultaneous increase of ISI (to 57 conventional units) and RPPWa (to 11.8 m/s). /91

Also, as in the CC-II, the FCC in the tests in the flight period for the FE-II significantly exceeded the preflight level. Beginning with the 50th day of flight, its maximum values with negative pressure varied in the narrow range of 86-92 beat/min (preflight -- 65-72 beat/min), and the negative increase on days 85-137 also was considerably greater (22-31% as opposed to 18% preflight). In the preflight period, in the tests made on the eve of the launch, in this cosmonaut significant changes in hemodynamic indices were recorded. As a rule in their intensity with rare exceptions they exceeded changes obtained in the flight tests. This exception was a test on day 137 when a /92 more marked phase syndrome of the functional hypodymania was noted (increase in the IC phase by 0.015 s, shortening of the PE by 0.063 s to the very small value of 0.222 s, an increase in the ratio of IC/PE by 0.111, as opposed to maximum preflight changes, respectively, +0.01 s, - 0.045 s to 0.240 s, + 0.07s).

A rheographic study showed that negative pressure of varying degrees expresses a decrease in the index of pulse blood filling of the vessels of the head; this was accompanied by marked vasoconstricting reaction. In the FE-I, under the effect of LBNP, a decrease in blood filling of the vessels of the head in all flight tests (particularly on days 14 and 92) was more marked than the preflight and in the CC-II did not go beyond the limit of the preflight reaction In the CC-I and FE-II, the large degree of decrease in pulse blood filling was noted only in tests on day 50 of the flight.

Thus, the reaction of the blood circulatory system to the effect of LBNP was shown by:

-- an increase of FCC;

-- the mean changes of the AP indices: an increase in minimum and mean and a decrease in lateral, terminal and pulse AP. In certain cases, signs were noted of vascular depression (decrease of all indices of AP, as for example in the CC-I on day 14 of the flight) for the opposite reaction (increase in the AP index, as for example in the CC-II on day 50--137 of the flight);

-- development of a phase syndrome of functional hypodynamia (lengthening of the IC phase, shortening of the PE and an increase in the IC/PE ratio);

-- decrease in the indices of mean ejection;

-- an increase in specific peripheral vascular resistance and RPPW along the aorta;

-- the decrease in indices of blood filling of the vessels of the brain accompanied by a marked vasoconstricting reaction.

During the flight reactions which were more marked in comparison /93 with the preflight tests under the effect of LBNP occurred which were more apparent in the CC-I on day 14 and the FE-I on days 14 and 92 and on the separate index on days 60 and 77 in the CC-II on days 85 and 137 basically according to the FCC data and the phase structure of the cardiac cycle; in the FE-II, most of the indices except for the FCC did not go beyond the limits of the preflight variations. A large number of the studies concern the physiological significance of the effect of LBNP on the cardiovascular system. As was already pointed out in model experiments, the effects of LBNP is accompanied by redistribution of blood in the lower parts of the body and its pooling in the vessels in the decompression zone which results in a decrease in the volume of circulated blood, a decrease in venous return of blood to the heart, a decrease in cardiac ejection [22,23,24]. A test for the effect of LBNP according to a number of characteristics simulates orthostatic perturbation [23,25] and in this connection it is used in flight for simulating a gravitational shift of the blood and an evaluation of orthostatic stability.

The basis for the decrease of orthostatic stability is the vasodepressing effect whose development, in the opinion of a number of authors, can be due to an insufficiency both of functions of the resistive vessels and the compensator contraction of the veins [26], extravascular dehydration [27] and also the vasodepressor reflex with intracardiac receptors [28]. The flight tests described did not show development of sharp vasodepressor phenomena although separately these characteristics were observed in the form of a decrease in the AP indices in the CC-I and CC-II on day 7 and in the FE-II on day 137. The symptoms of collapse observed in flight of the orbital Skylab station crew (using larger values of negative pressure) were completely absent in crew members on the Salyut-6 station. An increase in FCC and a drop in systolic indices of AP (for example, in the CC-I and FE-I on days 14 and 92) obviously was an expression of the decrease of stroke volume of blood and a significant increase in RPPW along /94
the aorta and facilitated bringing, according to the capacity of the arterial blood, the decrease under LBNP of the volume of actively circulating blood.

The changes of phase structure of the systole of the left ventricle which were apparent in the form of a so-called phase syndrome of functional hypodynamia, were observed only under LBNP and were absent in conditions of rest. This makes it possible to assume that the shift in the phase structure had a circulatory nature caused by lack of load on the chamber of the heart by the volume of blood. There is not always a precise parallel between the phase shifts and the deficit of volumes of hemocirculation when applying LBNP: significant changes in the phase are accompanied by a relatively small decrease in stroke volume of the blood (in the FE-I on day 77 and the CC-II on day 25 and in the FE-II on day 137 of flight). Probably this can be explained by the change in reactivity of the myocardium in expansion of its walls. Probably, in spite of the decrease in total volume of blood in rest conditions, its quantity in the upper half of the body actually was increased and thus facilitated a wide reservoir from which the blood was fed to the lower half of the body during application of LBNP. Lengthy hypervolemia of the upper sections of the body with increased load by volume on the heart adapted the contracting function of the myocardium to the new conditions. Limitation of inflow to the ventricle, relatively small in volume, under LBNP can be accompanied by shifts in the phase structure which are sharper than under ordinary conditions.

The expression of reaction to LBNP according to time periods for their manifestation and intensity have an individual character. For instance, in the crew members of MC-I, the signs of decrease of orthostatic stability observed on day 14 of the flight was due, apparently, to the fact that the test was made in a period of incomplete adaptation of the organism to conditions of weightlessness which is characterized by a significant stress on the regulatory mechanisms. Completion of the set of physical exercises recommended by the CC-I during flight later on obviously caused a gradual decrease in the reaction of /95 the cardiovascular system to LBNP and its recovery to the preflight level. On the other hand, in the FE-I, a certain decrease in transferability of LBNP was observed such as a characteristic of detraining of the cardiovascular system due to insufficient physical exercise during flight (the cosmonaut carried out physical training according to his own plan in the form of avoiding the loads which would cause an excitation effect on the cardiovascular system). The fact that the FE-I by the third month of flight had begun to fulfill the recommended volume of physical exercises, apparently, explains the relative decrease in transferability of the test with LBNP for the final stage of the flight.

In members of the MC-II, an increase in reaction to LBNP in-flight was apparent mainly in a chronitropic function of the heart and the phase structure of the cardiac cycle. One should note that for the entire extent of the flight, signs of an increase in positive inotrophic effects on the contracting capability of the myocardium were retained in all the cosmonauts in the initial state; the nature of this is still not completely clear. It is thought that as a result of increasing the volume of blood in the chest cavity and the detraining of the mechanisms of venous recovery, the application of LBNP causes a greater distribution of blood to organs of the abdominal cavity and the lower extremities than it does on Earth. This can decrease the activity of the receptors of the cardiopulmonary region and in a reflex manner increase the activity of the vasomotor center. As a result, adrenergic effects are increased [30]. One must not exclude the fact that intense physical training which was done by this crew facilitated maintaining a blood volume close to that on Earth. In certain cases, under the effect of LBNP, one observed an increase in the lateral systolic and pulse AP, insignificant changes or absence of them in the IC phase and a certain increase in cardiac ejection which, obviously, was evidence of the manifestation of a hypercompensatory reaction accompanying the increase in output of blood to the vascular channel due to pooling of /96 the blood in the internal organs.

In the postflight period, studies were made of the reaction of the organism to orthostatic effects. In all of the cosmonauts there was a decrease in orthostatic stability which was confirmed by a FCC value, shortening of the PE, a decrease in the index of cardiac ejection all larger than preflight. The duration of the decrease in stability in crew members of the MC-II was longer (seven weeks) than in the MC-I (three weeks). One should give attention to the peculiarities of postflight orthostatic reaction. After the 96-day flight, after 3-5 weeks, hypertension reactions were observed and after the

140-day flight, one noted the opposite tendency. This can be evaluated as a sign of a more stable suppression of the antigravitation function of the blood circulatory system in the longer flight.

In conclusion one should note that these factors of the decrease of orthostatic stability, such as dehydration of the organism [31, 32] a decrease in the quantity of blood circulated [22,33], the decrease in content of intertissue fluid and a decrease in vascular tone [34, 35,36], the decrease in muscle tone [37], decrease in catecholamine and mineralocorticoid exchange [38,39], fatigue of one type or another could all take place in conditions of long term orbital flight. However, maintaining physical training at the required level and the absence of disturbance in the work and rest routine in flight to a great degree increases the protective properties of the organism for a simulated hydrostatic load.

2.1.4. Results of Studies During Tests with Measured Physical Load and their Discussion. /97

When conducting tests with a measured physical load (MPL), the cosmonauts did not complain of feeling unwell. The pedaling power as a whole was maintained fairly precisely, and deviations in most tests did not exceed ±6%. However, there were cases when the cosmonauts did not maintain the necessary number of revolutions in pedaling and due to this the FE-I in the tests on days 30 and 42 had a total load less than 26-29%; in the CC-II it exceeded the required value on days 97 and 119, respectively, by 10 and 31%, and in the FE-II, an excess was observed on day 119 by 9%. One should note that when working on the bicycle ergometer, for the FE-I, there was a characteristic tendency toward completing it less intensely and in the CC-II, on the other hand, there was a more intense routine of pedaling. The CC-I and FE-II maintained a total value of the load fairly precisely.

The frequency of cardiac contractions in most flight tests in the members of both crews, in their absolute value, exceeded the mean preflight level both in the initial state (except for the CC-I) and under physical load (Figure 1). Whereas preflight the maximum values varied in a range of 110-126 stroke/min (in one case in the CC-I less than 135 stroke/min), in the flight tests these variations amounted to 108-152 stroke/min. In recalculating for mean values in all tests, in four of the cosmonauts in the preflight and flight periods, this relationship amounted to 116.7 stroke/min and 123.5 stroke/min, that is, more than 6%. Then, the maximum increase in FCC in the preflight tests amounted to +67-104% (on the average +83.7%) and in flight +57-171% (on the average +86.7%). Consequently, the averaged data did not show significant deviations in the increase in FCC during or before operation and in-flight. An analysis of individual changes in FCC indicated that in the CC-I, only with a load on day 30 did one note a higher absolute level of FCC (up to 141 stroke/min, preflight maximum up to 135 stroke/min), and on days 7, 30 and 43, a higher relative increase in FCC /99 (respectively, +100, 143, 96%; preflight +87%). The higher absolute

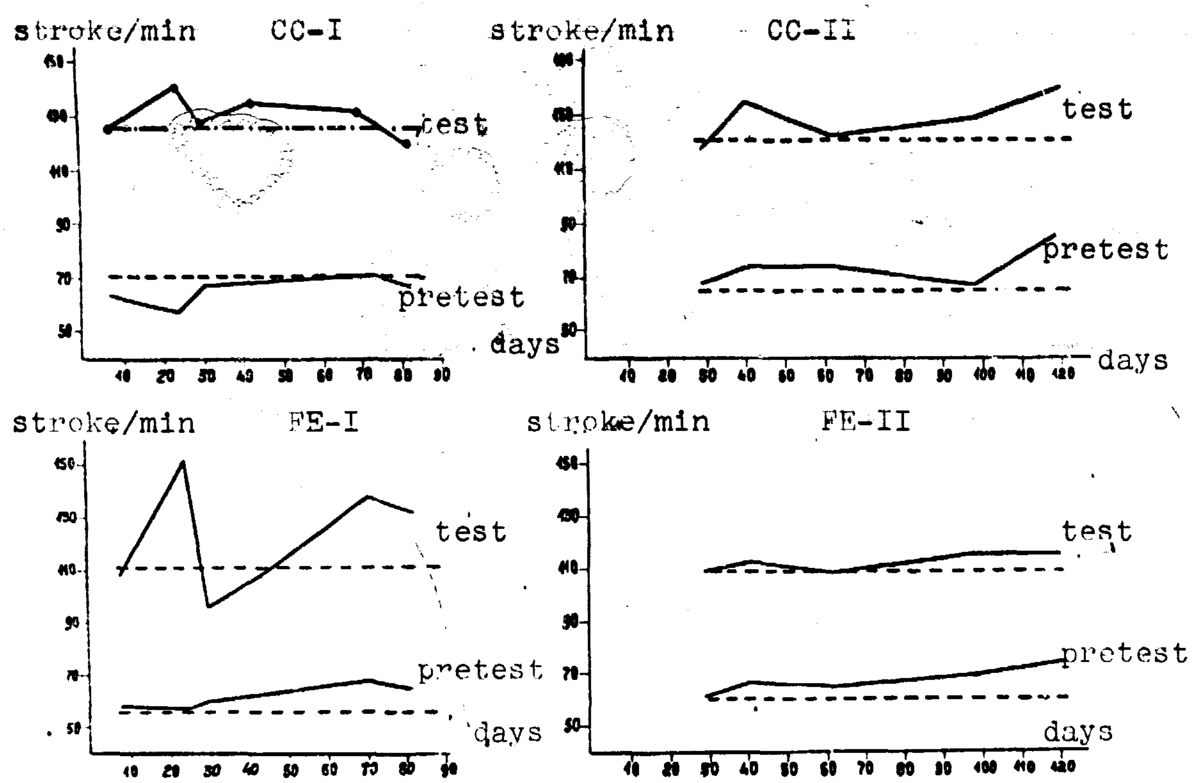

Figure 1. The dynamics of frequency of cardiac contractions when carrying out tests on the bicycle ergometer in flight.

Symbols:

- - - - – mean value of frequency of cardiac contractions in the preflight period before the test;

-o-o-o – maximum value of frequency of cardiac contractions in the preflight period during the test;

______ – mean value of frequency of cardiac contractions inflight before the test;

-o-o-o – maximum value of frequency of cardiac contractions in flight during the test;

CC-I and CC-II – commanders of the first and second main crews;

FE-I and FE-II – flight engineers of the first and second main crews.

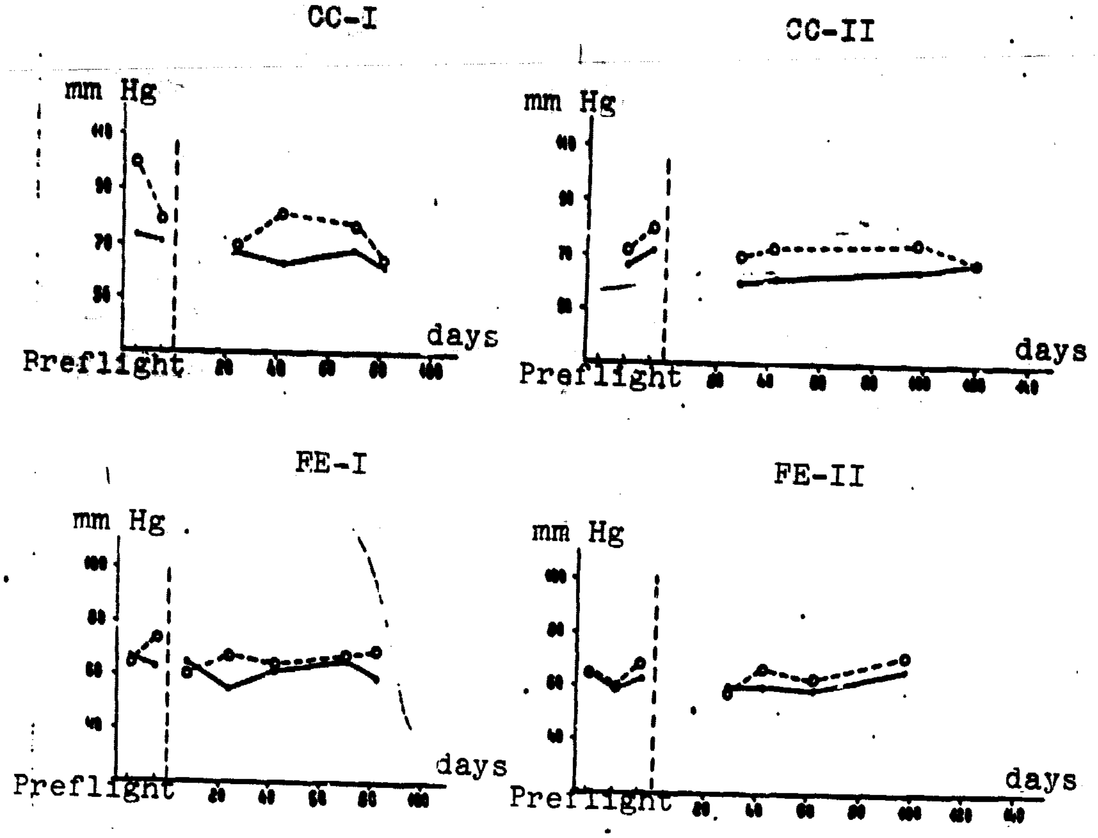

Figure 2. Dynamics of minimum arterial pressure in-flight when conducting tests on a bicycle ergometer.
Symbols:
______ - mean values of the indices before the test;
o-o-o- - values of the index at minute 1 of the recovery period;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

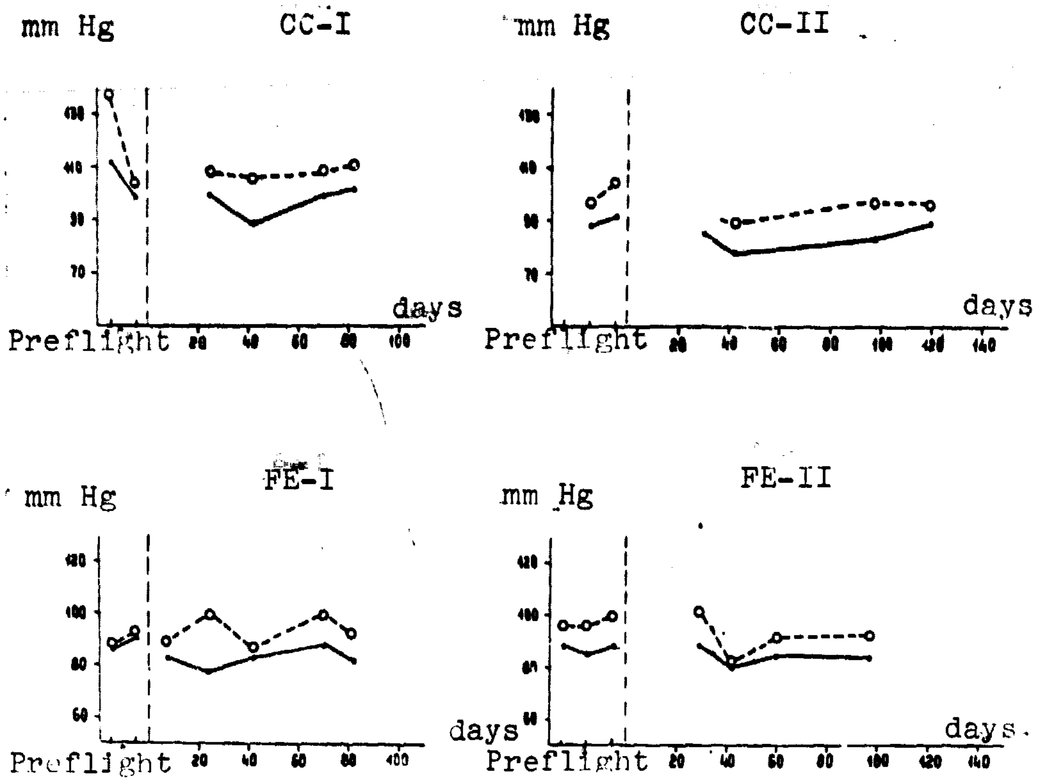

Figure 3. Dynamics of mean arterial pressure in-flight when conducting tests on the bicycle ergometer.
Symbols:
______ - mean values of the index before the test;
o-o-o- - values of the index at minute 1 of the recovery period;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

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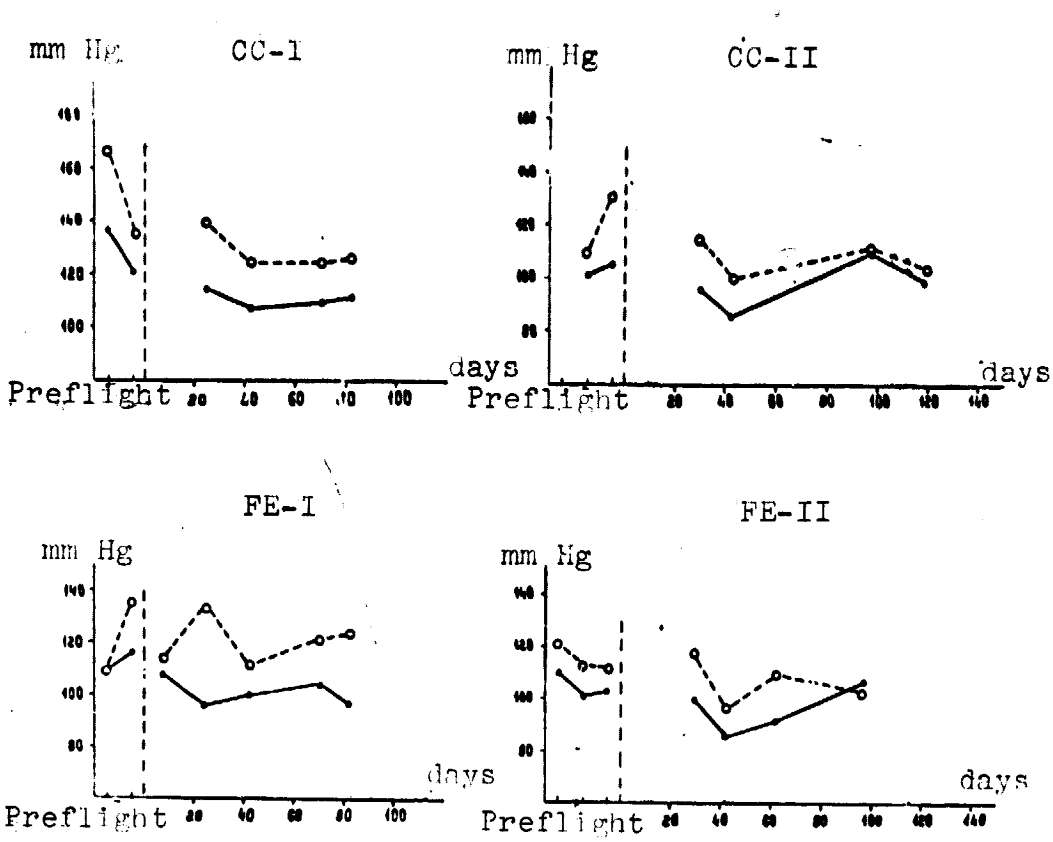

Figure 4. Dynamics of the lateral systolic arterial pressure in-flight when conducting tests on the bicycle ergometer.
Symbols:
______ - mean values of the index before the tests;
o-o-o- - values of the index at minute 1 of the recovery period;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

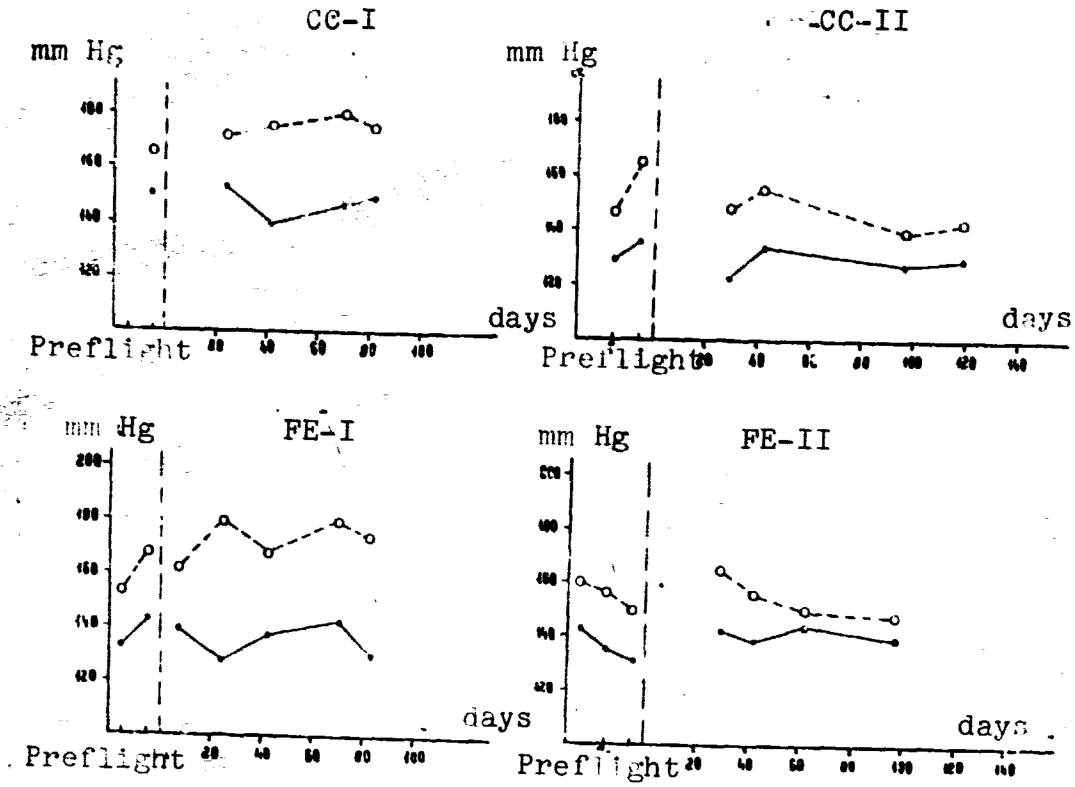

Figure 5. Dynamics of the terminal systolic arterial pressure in-flight when conducting tests on the bicycle ergometer.
Symbols:
______ - mean values of the index before the test;
o-o-o- - values of the index at minute 1 of the recovery period;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

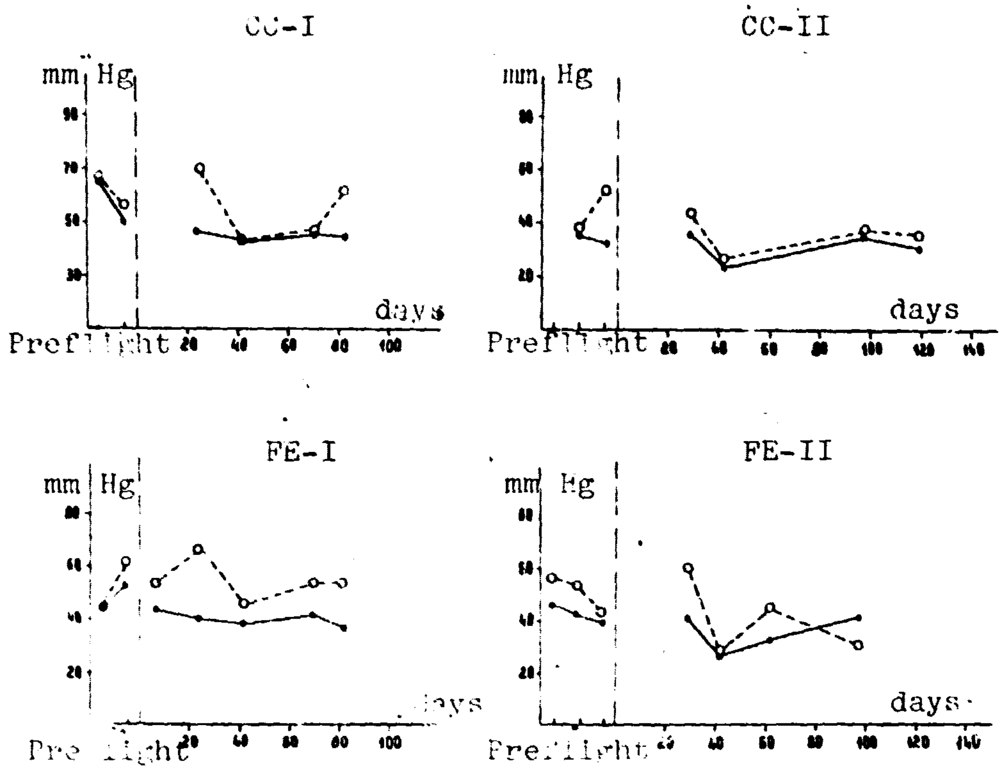

Figure 6. Dynamics of pulse arterial pressure in-flight when conducting tests on the bicycle ergometer.
Symbols:
_____ - mean values of the index before the test;
o-o-o - values of the index at minute 1 of the recovery period;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

values of FCC in the FE-I were fixed on days 24, 70 and 82 (respectively, 152, 138 and 130 stroke/min, prefligh 113 stroke/min), however, the relative increase exceeded the preflight data only on day 24 (+171% as opposed to +104% preflight). In the CC-II, also in tests on days 41 and 119, one observed differences in the absolute maximum values of FCC under load (respectively, 135 and 140 stroke/min, preflight maximum 126 stroke/min). In the FE-II, none of the flight tests of FCC was higher than with preflight loads. In both MC-II crew members in the flight tests, the relative increase was smaller than with maximum ground changes of FCC. The dynamics of the ratio of the total value of FCC to the total value of power obtained in 5 minutes of the test indicated that in the preflight period, the largest values of this ratio were found in the CC-I (less than 0.18), however, in flight none of the tests showed an excess of this boundary. In the FE-I, in the tests on days 24, 42 and 70, the ratio amounted to respectively, 0.20, 0.19, 0.17, which significantly (by 15-33%) exceeded the preflight level of this index. In members of the MC-II, variations in this ratio did not differ significantly from the preflight values and on days 29, 62 and 119, the values of the index were even smaller than in the preflight tests (by 6-15%), particularly in the final stages of flight. In the tests on day 29 (in the FE-II) and on day 41 (in the CC-II) of flight, recovery to the initial level was slow. The output of FCC in a stable state during load during preflight and in-flight tests showed that, as a rule, in 2-3 min, the pedaling and length of flight do not significantly affect the rate of work.

In the recovery period, the FCC in 5 minutes in the preflight period in MC-I crew members did not reach the initial level, exceeding it by 10-26%. In the flight tests, one could not always successfully trace the process of **recovery** to the end; however in those cases /100
where it was recorded for 4-5 minutes, a relatively more rapid rate of recovery was determined than in the preflight. An exception was the dynamics of FCC in the FE-I on day 24, when in 5 min, the level of the FCC exceeded the initial by 31 stroke/min (or was 55% larger). In the CC-II in only one case (on day 97) the FCC did not reach the initial value, exceeding it by 13 stroke/min (by 19%). In the FE-II in certain tests, in which the dynamics of FCC were traced for up to 5 minutes, the excess amounted to 11-16%.

The indices of arterial pressure, recorded in 1 min after completion of **operations by the** cosmonauts, also changed ambiguously (Figures 2-6). In comparison with the maximum preflight reactions, the increase in the AP indices in the CC-I and CC-II in the flight test did not go beyond the limits of the ground variations. An exception was the more marked increase of pulse AP i the CC-I on days 24 and 82 (+38%, preflight +5-12%) and in the CC-II, the increase of minimum AP on day 41 (+19%) and day 97 (+15%, preflight +9-11%).

The most significant changes in AP in response to load were obtained in the flight tests on the FE-I. The absolute increase in minimum AP in him did not differ from the preflight; however, its relative increase on day 24 was somewhat greater (+24% as opposed to +17% preflight). In the tests on days 24 and 82, one noted in him

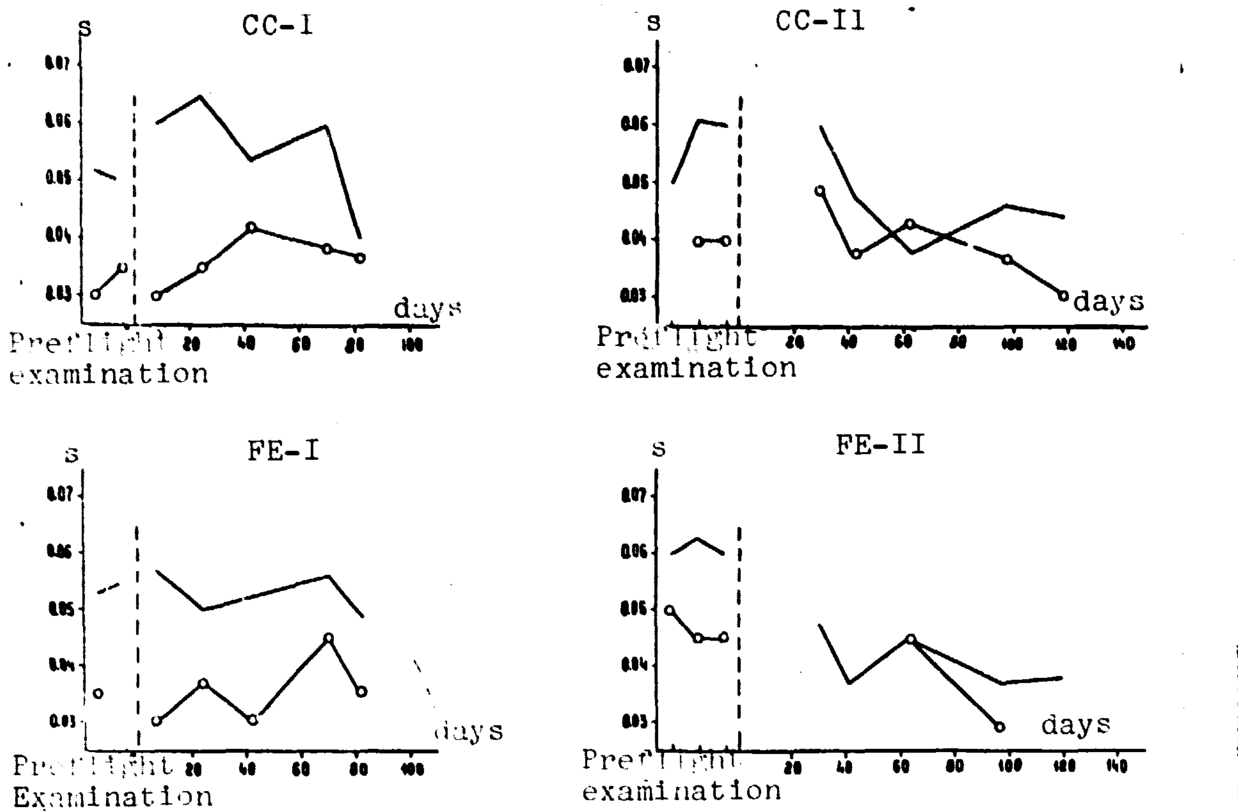

Figure 7. Dynamics of the duration of phase of isometric contraction of the left ventricle when conducting a test on the bicycle ergometer in-flight.

Symbols:

______ - values of the index before the test;

o-o-o- - values of the index at minute 1 after the test;

CC-I and CC-II - commanders of the first and second main crews of the orbital Salyut-6 and Soyuz complex;

FE-I and FE-II - flight engineers of the first and second main crews of the orbital Salyut-6 and Soyuz complex.

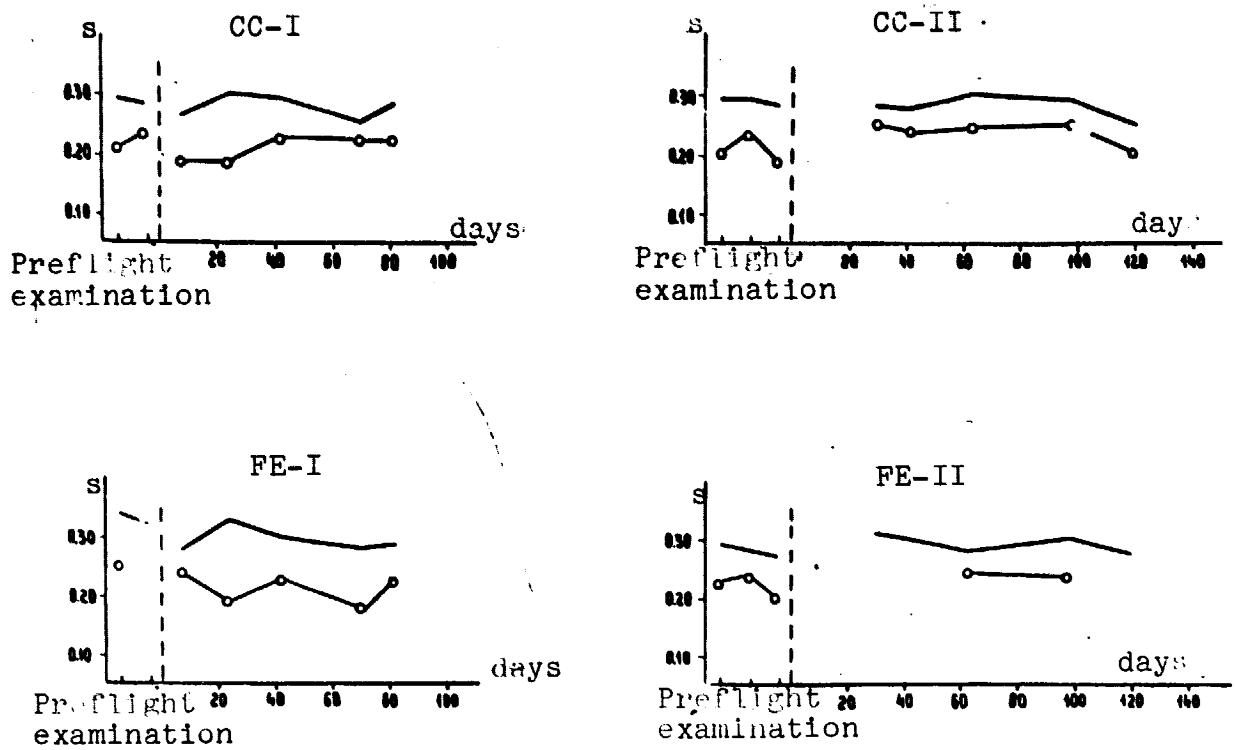

Figure 8. Dynamics of the duration of the ejection period of the left ventricle when conducting tests on the bicycle ergometer in-flight.

Symbols:

______ - value of the indices before the test;

o-o-o- - values of the indices at minute 1 after the test;

CC-I and CC-TI - commanders of the first and second main crews of the orbital Salyut-6 and Soyuz complex;

FE-II and FE-II - flight engineers of the first and second main crews of the orbital Salyut-6 and Soyuz complex.

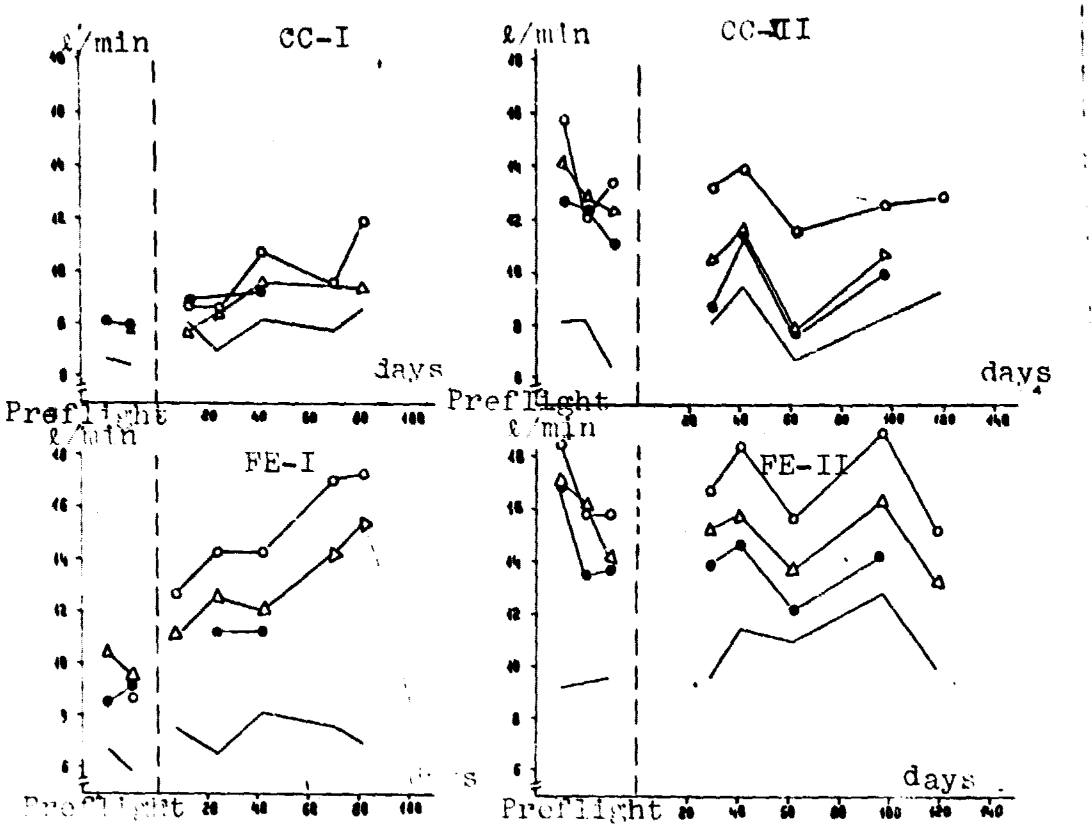

Figure 10. Dynamics of minute volume of blood circulation when conducting tests on the bicycle ergometer in-flight.
Symbols:
______ - values of the index before the test;
o-o-o- - values of the index at minute 1 post-test;
Δ-Δ-Δ- - values of the index at minute 2 post-test;
o-o-o- - values of the index at minute 3 post-test;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

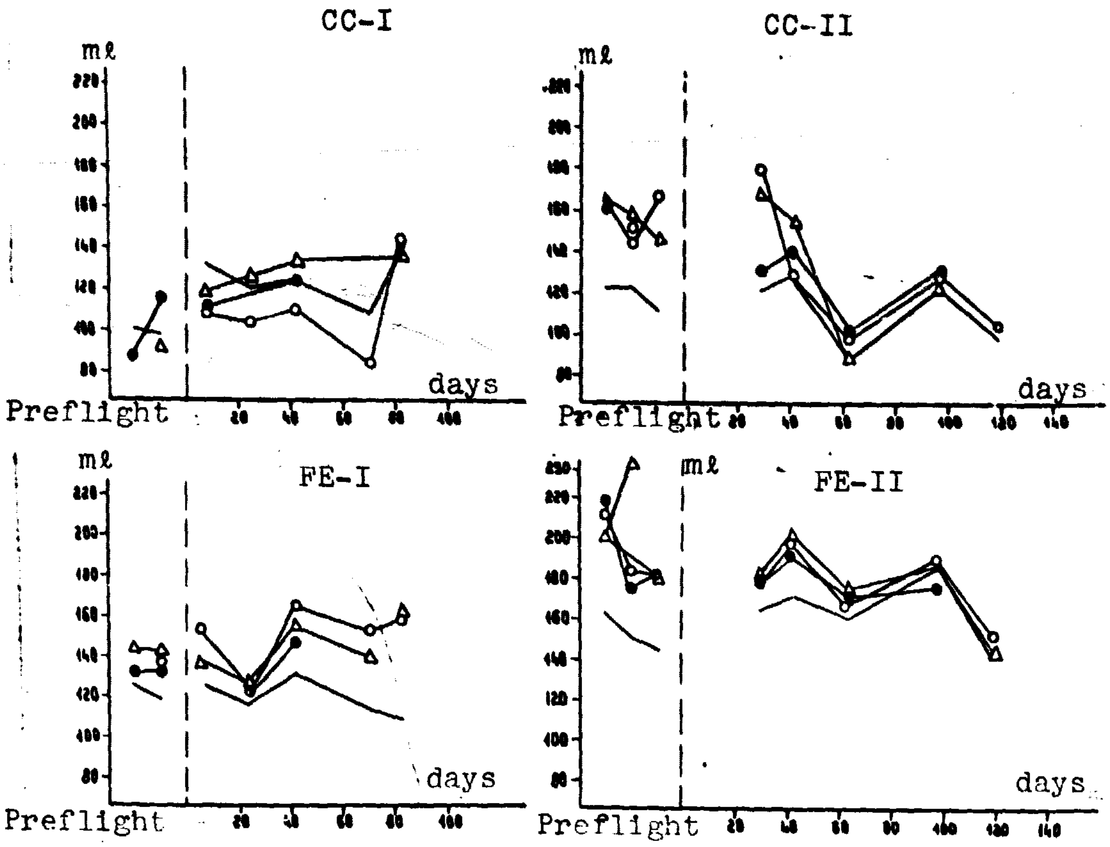

Figure 9. Dynamics of the :roke volume of the heart when conducting tests on the bicycle ergometer in-flight.
Symbols:
______ - value of the index before the tests;
o-o-o- - value of the index at minute 1 after the tests;
Δ-Δ-Δ- - value of the index at minute 2 after the tests;
o-o-o- - value of the index at minute 3 after the tests;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

[Translator's note: In Figures 9-12, the author does not differentiate between the clear and dark circles on the Figures.]

a significantly more marked increase in other indices of AP: mean dynamic (respectively, +30 and +16%, preflight +2-3%), lateral (respectively, +41 and +28%, preflight +1-17%), terminal (respectively, +33 and +34%, preflight +15-17%). One should note that in this cosmonaut the increase of mean AP (except the test on day 42) and the terminal AP (except the test on day 7) was in all the flight tests more marked than the preflight. The greatest shifts toward an increase were observed in the FE-I for pulse AP: this increase also in all of the flight tests (except the test on day 7) was larger than in the preflight period (+21-46%, preflight +5-17%). In the FE-II, on days 29 and 62, the absolute and relative increase of lateral AP /106 exceeded the preflight increase (an increase of relative initial level at 18 mm Hg or by 18-20%, the preflight increase by 11 mm Hg or by 11%). There was an uncharacteristic decrease in the AP pulse index after load (at minute 1) in comparison with the initial data observed in the FE-II on day 97.

Changes in the phase structure of the systole of the left ventricle (Figures 7, 8) were apparent immediately after load in the form of a phase syndrome of hyperdynamia [9] (combined shortening of the phase of isometric contraction and the period of ejection of blood by the left ventricle). In the preflight period, shortening of the IC phase in four cosmonauts of the MC-I and II varied within limits of 20-45% in the ejection period -- 14-35%. The decrease in the ratio IC/PE in three cosmonauts in the preflight test was approximately uniform (-14 to 19%) and only in the FE-I did it reach -35%).

In the flight tests, more abrupt shortening of the phase indices in comparison with the preflight dynamic was observed in one or two minutes only in members of the MC-I and in both cosmonauts these changes in the IC phase were fixed in tests on day 7 (by 50-59%) and the duration of PE on day 24 (by 33-40%). A more marked shortening of the PE was noted in the FE-I also on day 70. In accordance with the changes of the indicated phases of the systole a change was noted in their ratio. A more marked decrease of this index was observed in the CC-I on days 7 and 70, in the FE-II on day 7 in the CC-II on day 62. In several tests, the ratio of IC/PE increased by 19-33% (in the CC-I on day 82, in the FE-I on days 24 and 70, in the FE-II on day 97) basically due to relatively small shifts in the IC phase.

The dynamics of stroke volume of the heart and minute volume of the blood circulation (Figures 9,10) in members of the MC-I and II immediately after load had significant individual variations. For the CC-I both before and during flight, an average degree of increase of MVC was characteristic with an ejection of 7-40%, and in most of the tests, the initial period of recovery was accompanied by a decrease in SV (by 12-23%). In the FE-I, in comparison with the ground reaction, in all flight tests one observed a significantly more marked increase in SV (except day 24) and in MVC (SV +22-44%, preflight maximum +16%, MVC +74-173%, preflight maximum 66%). In the members of /111 MC-II the changes in volumes of hemocirculation, in comparison with preflight data either did not go beyond the limits of reactions which were observed in ground conditions or these changes were expressed to a lesser degree. In the CC-II, the increase in MVC in the flight

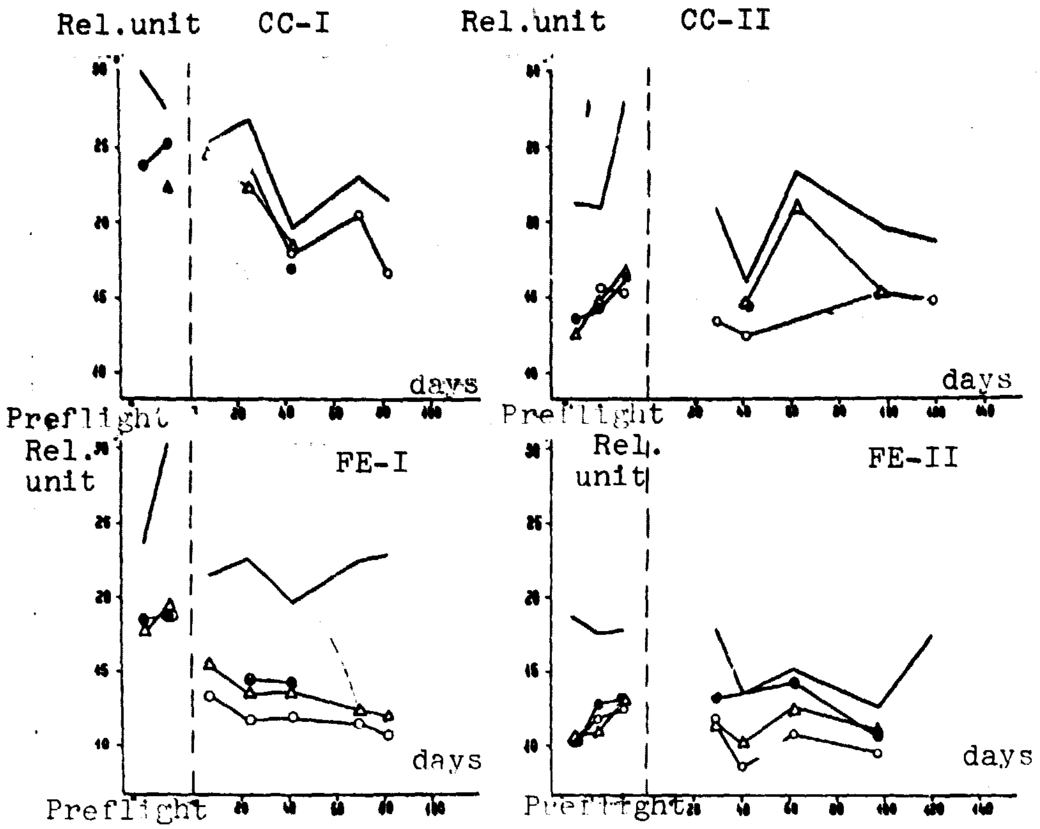

Figure 11. Dynamics of actual specific peripheral resistance when conducting tests on the bicycle ergometer in-flight.
Symbols:
______ - value of the index before the test;
o-o-o- - value of the index at minute 1 after the test;
Δ-Δ-Δ- - value of the index at minute 2 after the test;
o-o-o- - value of the index at minute 3 after the test;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

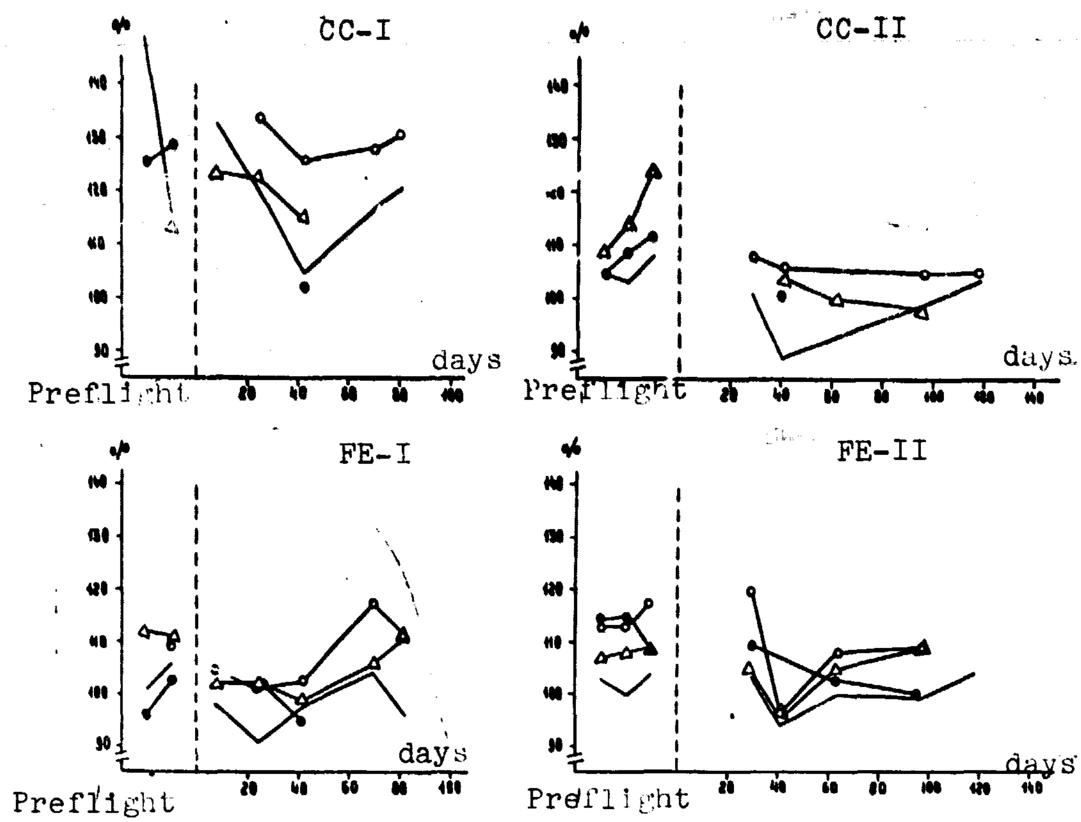

Figure 12. Dynamics of the ratio of actual specific peripheral resistance to the required specific peripheral resistance when conducting tests on the bicycle ergometer in-flight.
Symbols:
_____ - values of the index before the test;
o-o-o - values of the index at minute 1 after the test;
Δ-Δ-Δ - values of the index at minute 2 after the test;
o-o-o - values of the index at minute 3 after the test;
CC-I and CC-II - commanders of the first and second main crews;
FE-I and FE-II - flight engineers of the first and second main crews.

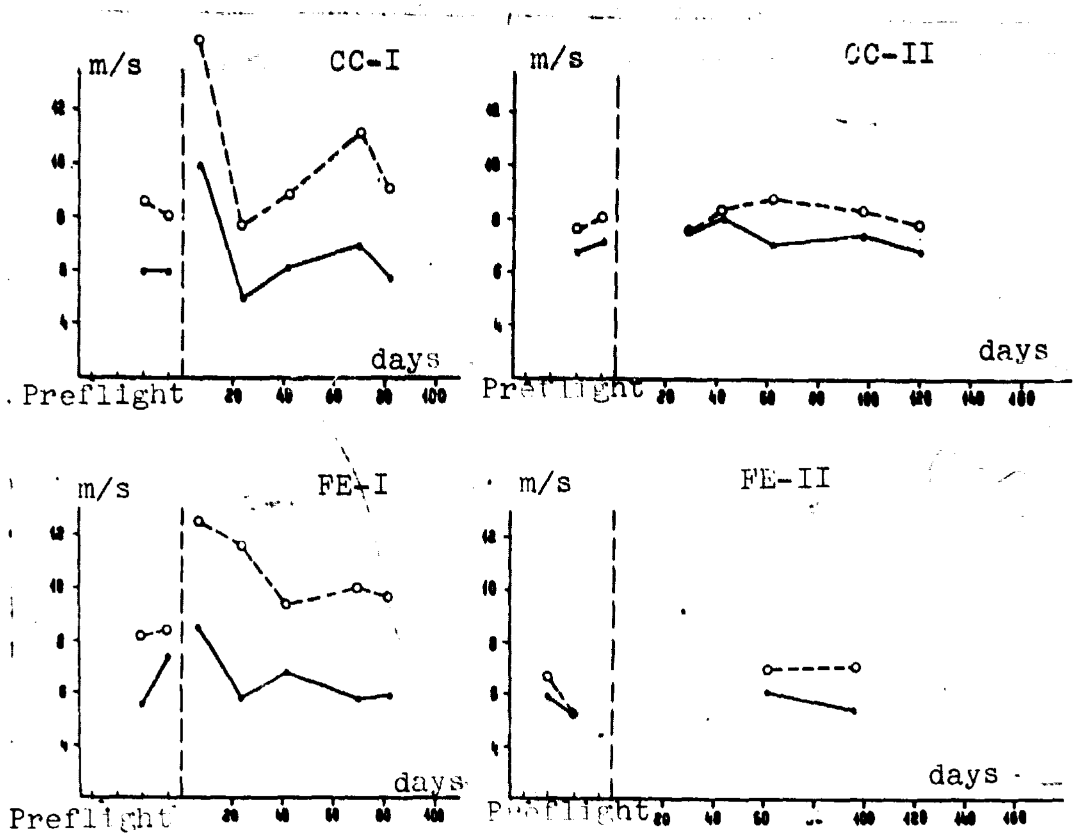

Figure 14. Dynamics of the rate of propagation of the pulse wave along the aorta in-flight when conducting tests on the bicycle ergometer.

Symbols:

______ - mean values of the index before the test;

o-o-o- - values of the index at minute 1 of the recovery period;

CC-I and CC-II - commanders of the first and scecond main crews;

FE-I and FE-II - flight engineers of the first and second main crews.

tests varied within limits of 39-77%, preflight it reached 109%; in the FE-II, the increase in MVC in-flight amounted to +43-73%, preflight maximum was 101%. It was characteristic that in both cosmonauts the increase in SV in the tests in the second half of the flight decreased to +5 to -2% (preflight +18-65%) and the increase in MVC basically occurred due to tachycardia. /111

The specific peripheral resistance (Figure 11) in all cases at minute 1 after load was decreased. The ratio of actual values of SPR to the required (Figure 12) in response to load increased in flight, as a rule, to a greater degree than preflight. It is surprising that the increase in required values in three cosmonauts (except FE-II) increased after load in tests in the final stages of flight. In the FE-I, also phenomena were traced for the extent of all test flights (except on the test on day 7). In most of the flight tests on him (particularly on day 82) the degree of decrease of SPR was greater than in the preflight period (-38 to 53%, preflight, -38%).

The rate of propagation of the pulse wave along the aorta at minute 1 after load was higher than the initial (Figure 13). In members of the MC-I, the increase in RPPWa was more marked than in members of the MC-II both in the preflight (on the average MC-I +34%, MC-II +17%) and in the in-flight tests. Then, in both crew members of the MC-I, the increase in RPPWa immediately after load in most in-flight tests was stronger than the preflight. In the CC-I, the increase in the flight amounted to 46-60% (preflight +35-43%), in the FE-I the index increased in flight in all tests (except the test on day 42, +38%) by 48-99% (preflight by 13-47%). The most significant changes were noted in him on days 24 and 70 of the flight. In the members of the MC-II in the majority of tests the increase in RPPWa did not exceed /115 the preflight. An exception was the somewhat larger increase in the index in the CC-II (by 25%, preflight by 14%) on day 62.

The data presented indicate that the transferability of load tests in the four cosmonauts was ambiguous during flight and the character of the reaction of the blood circulatory system had a definite individual character. One should note that the markedness of the reaction of the cardiovascular system to load in the MC-I crews as a whole was larger than in the MC-II crews. Here the most significant shifts in the indices of hemodynamics were detected in the FE-I. Whereas in the CC-I the reaction to load was apparent basically in a more marked relative and/or absolute increase in FCC, in the FE-I the changes in the indices had a marked [illegible]plex character.

During analysis of the data, attention was given to the phase aspect in the character of manifestations of reactions to load in members of the MC-I. On day 7, both cosmonauts underwent the test well. A peculiarity of the reaction in [illegible] members was a more marked shortening of the IC and in the C[illegible]-I -- a decrease after load of the AP indices which, apparently, was a symptom of an accepted decrease in the peripheral vascular resistance which caused a decrease in stroke volume and a low value of MVC. One can propose that the indicated phenomena become possible in conditions of a decrease in volume of circulatory blood. On day 24, in both MC-I cosmonauts, clear signs of an increase in reaction of blood circulation to load were established. This was apparent in the development of more marked tachycardia, sharper than preflight shortening of PE, an increase in the indices of AP, RPPW along the aorta, and in the FE-I -- in an increase in the volume of hemocirculation and a decrease in peripheral resistance whereas with an increase in required value of SPR which was evidence of a certain lack of correspondence of the volume of the arterial bed and the actual cardiac ejection. On day 42, in both members of this crew one also noted a marked chronotrophic reaction of the heart to load in comparison with the preflight period. Here, /116 the increased frequency of beating of the heart in the FE-I was inadequate to load which in a given test was below that planned; due to this the ratio of FCC to the power increased significantly. The signs of inadequacy of the reaction of the cardiovascular system to the load applied was retained in the FE-I in the test on day 70. The more marked absolute increase of FCC exceeded in its value (in recalculation at the power level) the increase observed in the Earth tests and its recovery to the initial level was not observed 5 minutes after the load. Changes in systolic AP, duration of PE, RPPW along the aorta and SPR differed significantly from the preflight data. It is surprising that in the tests on days 24 and 70, in the FE-I immediately after the load, an increase was noted in the IC/PE ratio due to insignificant changes in the IC phase. In the conditions of significant redistribution of blood due to muscle work, the indicated symptoms can be reevaluated as a manifestation of symptoms of relative hypodynamia of the left ventricle. In the tests on day 82, although one noted a more favorable reaction to physical work; however, in the CC-I also an increase in the IC/PE ratio was recorded and in the FE-I a more marked increase in FCC and systolic AP, and also a decrease in SPR; then in both, an increase in the pulse AP also was much sharper.

Thus, in members of MC-I on days 24-43, and in the FE for an even longer period, in accordance with the dynamic index of blood circulation, one noted a relative decrease in work capability. A negative characteristic of the reaction in flight to physical load in members of the MC-II was the absence of sharp deviations from the preflight reactions and the absence of a notable interaction between them or any shifts in the indices during the tests with long term flight, that is, the phase characteristic graphically apparent in members of the MC-I was practically absent in members of the MC-II. More noticeable deviations from preflight reactions in-flight were apparent in the CC-II: in several extended recoveries of FCC on days 41 and 97 and /117 systolic indices of AP on day 41, a sharper decrease in the IC/PE ratio and an increase in RPPWa on day 62, somewhat more marked tachycardia on day 11[illegible], which was adequate for more pedaling power. As has been pointed out, the CC-II, as a rule, carried load with a large value of work which indirectly indicated retention of good physical training.

Changes in the FE-II led to his reaction to load in two cases (on days 29 and 62) which were accompanied by a more marked increase in lateral AP and in a certain relative slowdown in the recovery after load of the FCC and AP values (on day 29). In spite of the fact that in the MC-II crew members, transferability of the load tests was retained at a fairly high level, the elements of detraining were noted in this crew. In both cosmonauts this was apparent in the formation of an increase of minute volume of blood circulation in response to load due to an increase in FCC and a relative decrease in the role of stroke volume.

The use of functional tests with measured physical load in flight conditions was basically directed at determining the degree of physical condition of the organism of the cosmonauts. A comparison with the state in the preflight period made it possible to discover how both the detraining effect of weightlessness and the phenomena of a retraining under intense physical exercises occurred. One should, however, note that the preceding studies both of the Soviet and American specialists in flight conditions did not show serious changes in transferability of physical load by the cosmonauts. The American scientists did not observe any tendency which would indicate worsening of the reactions of the cosmonauts in flight tests [40,41]. With a three stage test with submaximum load carried out on the Skylab orbital station, significant changes in hemodynamics were apparent in a relative (in comparison with preflight data) decrease in FCC in the period of recovery and a decrease in diastolic AP at a state of rest, under load and during recovery. It was noted that the quantity of physical /118 work completed during flight is inversely proportional to the length of the period of readaptation after return [41]. However, the problem of determining the criteria of detraining and retraining remains fairly acute inasmuch as postflight studies, as a rule, show a significant decrease in work capability.

The work completed by members of the Salyut-6 orbital station in flight tests was accompanied by a normal tonic reaction of the indices of the cardiodynamics and hemodynamics in which the conjugate aspect and parallelism of changes in FCC and AP, that is, increased frequency of the pulse occurred simultaneously with fairly marked increase in pulse amplitude due to an increase in systolic and average decrease of diastolic AP [43]. Small changes in the systolic (lateral) AP at minute 1 of recovery which were observed in the CC-II on day 119 (+5 mm Hg) and in the FE-II on day 97 (-4 mm Hg) led one to propose a deviation in the indicated cases for the development of reactions from the normal tonic type toward a hypotonic type. In the opinion of specialists in the field of sports medicine, this type of reaction must be accompanied by a significant quickening of the pulse rate [42]. In the situations considered, the increase in FCC was not significant in the FE-II (115 stroke/min) and increased significantly in the CC-II (up to 140 stroke/min). The latter was also caused by a large value of physical load. One of the causes of the small reaction of AP could be the fact that the changes in systolic (lateral) AP, determined by a method of tacho-oscillography, in response to load was much weaker than changes in maximum AP obtained by the auscultative method [44]. Another explanation could be a decrease in venous return of the blood to the heart cavity and the stroke volume as a result of contraction of the volume of actively circulating blood [40].

One should note that in the study indicated of the FE-II, shortening of the IC phase (at minute 1) was relatively smaller than in the preflight examinations and even after 2 minutes its duration corresponded to the initial value. This, apparently, can indicate although not precisely enough, the presence of signs of a functional hypodynamia of the myocardium from lack of load on the cardiac by the volume. /119

As has been pointed out, studies [45], marked expression of shifts in the work of the blood circulatory system depend on the power of work done in the fixed routine. A decrease in power (less than 500 kgm/min) is accompanied by a sharp prolongation of the initial period of stabilization with an increase in power (up to 1700 and more) the period of work rapidly is shifted by the period of stabilization. The working-in period with output of FCC in the established state (steady state) in all four cosmonauts in flight differed little from the preflight and, as a rule, was observed at minutes 2-3 of pedaling. One should note that determination of the moment of stabilization of FCC was not clear in all cases. In the FE-I, in whom as was pointed out earlier the reaction of cardiadynamia during flight was more marked, a clear moment of output of FCC to the plateau was not established on days 24 and 70. Due to the fact that in these tests the value of power approximately corresponded to that planned and in the preflight tests the moment of working out was fixed at minute 3, one can propose that prolongation of the process of working out in certain cases reflected a definite degree of detraining.

Another factor causing development of symptoms of physical detraining is the change in character of maintaining an adequate level of cardiac ejection in response to load by increasing the chronotropic function of the myocardium. It is well known that for trained athletes a more significant systolic reserve is characteristic than for the untrained. Therefore, depending on the degree of training, the interrelationship changes in the formation of MVC between the increase of FCC and VS, that is, the trained subject with average load uses the systolic reserve without a sharp increa e in FCC [46]. As detraining develops, the role of the chronotropic function of the heart increases.

Summarizing the results obtained of the tests with physical load one can state the following facts: /120

-- in all MC-I and MC-II crew members, in-flight symptoms of detraining of the cardiovascular system were determined to one or another degree; this was apparent in the increased reaction of cardiohemodynamics to load, in comparison with preflight data, and also changes in the structure of the phase of the cardiac cycle and an increase in the role of the chronotropic function of the heart in formation of cardiac ejection,

-- in MC-I crew members, as a whole, increase in the reaction to the test was apparent to a more marked degree than in members of the MC-II, and more significant shifts in the indices in the flight tests were noted in the FE-I in comparison with the preflight period,

C-2

-- changes caused by detraining of the organism of the cosmonauts in the MC-I had a definite phase character in development: they were larger in both crew members in tests during the first month of flight, and in the FE-I for practically the entire expedition. In the MC-II crew members there were no noticeable changes in phase shapes apparent, however, a progressive increase in chronotropic effect on productivity of the heart took place,

-- one can propose that the increase in reactivity of the cardiovascular system to physical load and the manifestation of symptoms of its detraining are in direct relationship to the volume of physical exercises of the cosmonauts in flight.

2.2. Study of the Reaction of the Cardiorespiratory System when Conducting Tests with Measured Physical Load Before and After Flight /121

Tests with physical load were carried out on a bicycle ergometer. Here, a gradually increasing load was used requiring switching of the degree of intensity 600 kgm/min.

First expedition. Members of the crew of the first expedition: commander (CC-I) and flight engineer (FE-I) in the preflight period endured two stage load well (600 kgm/min X 3 min + 750 kgm/min X 3 min).

On day 5 after landing both cosmonauts completed 3 minute work with intensity 300 kgm/min as preliminary testing with recording only of arterial pressure and electrocardiograms. On the 6th day the FE-I and on the 7th the CC-I completed tests with 3 minute work with intensity 600 kgm/min. Then, a whole complex of indices of the cardiorespiratory system were recorded. On the 12th day both crew members underwent one more test: the CC-I completed a two stage (600 kgm/min X 3 min + 750 kgm/min X 3 min), and the FE-I -- a three stage (300 kgm/min X 3 min + 600 kgm/min X 3 min + 750 kgm/min X 1 min).

Work on the bicycle ergometer after landing was not accompanied by any kind of breakdown in the functional state of the organism. At the same time, a definite worsening of regulation of the cardiorespiratory system was apparent in withstanding physical load. Thus, the cosmonauts with a load of 300 kgm/min subjectively perceived it as preflight 750 kgm/min. The basic indices of blood circulation and respiration in the third minute of load 600 kgm/min is presented in the Table.

First of all one should note in both cosmonauts the intensity of cardiac activity under physical load. Frequency of cardiac contractions and terminal systolic arterial pressure became large. Their product, the so-called cardiac load index [47] increased in the CC-I by 10%, in the FE-I by 28%, in comparison with the preflight data which showed an increase in consumption of energy of the heart in the work itself. The increase in cardiac activity was close to the preflight level of the minute volume of blood circulation and the oxygen requirement only in the CC-I; in the FE-I, these indices were lower than the preflight values by 8% and 11%, respectively.

The intensity of cardiac activity, and, apparently, the excess of sympathetic stimulation were apparent and shortening of the ejection period above the required for a given frequency of cardiac contractions had values in the CC-I at 11% and in the FE-I 28%. The effectiveness of cardiac activity decreased in relation to oxygen transport. Thus, the oxygen pulse decreased in the CC-I by 4% and in the FE-I by 16% in comparison with preflight data. Evaluating the reaction of the cardiorespiratory system of the cosmonauts to physical /122
load, one can note the common characteristic of change of the state of increase in intensity and the uneconomical aspects of its functioning. However, this increase in intensity provided the organism with an adequate supply of oxygen only in the CC-I, and in the FE-I it was decreased, and apparently, reflected worsening of the contractile capability of the myocardium.

Second expedition. The members of the second expedition: commander (CC-II) and flight engineer (FE-II) completed a record 140-day flight. Before the flight, they, like the members of the first expedition, underwent tests well on the bicycle ergometer. The recorded indices correspond to the reactions of a healthy person.

After the flight, the tests on the bicycle ergometer were made on the 7th day. Taking into account the state of their health there were two stages of load: 450 kgm/min X 3 min + 600 kgm/min X 3 min. Both of the crew members handled the load without any kind of unfavorable feelings. Then, the CC-II noted that he could have taken this load in the first day postflight.

Attention was given to increasing intensity of cardiac activity at rest in the initial postion. The frequency of cardiac contractions and arterial pressure were significantly increased. The cardiac load index exceeded the preflight values in the CC-II by 44%, and in FE-II by 75%. The lack of economy in functioning of the cardiorespiratory system was reflected by a decrease in the oxygen pulse in the CC-II by 22% and in the FE-II by 34% in comparison with their preflight values.

Considering the initial level of reaction to physical load, it was adequate in its intensity. For instance, the cardiac load index increased in the CC-I by 20%, and in the FE-II by 31% in comparison with the preflight values. But this increase was smaller than that in the initial condition at rest.

The intensity of cardiac activity was more marked in the FE-II. It was reflected by a decrease in the ejection period above that required for a given frequency of cardiac contractions by 18%. At the same time, the demand for oxygen was even increased by 11% in comparison with the preflight data. In the CC-II, the period of ejection corresponded to the required value and oxygen requirement was at the preflight level. Respectively, the increase in frequency of cardiac contractions was decreased by the oxygen pulse in the CC-II by 11% and in the FE-II by 8% in comparison with the preflight which reflected a decrease in economical cardiac activity. /123

After 7 weeks of readaptation, which occurred at a sanitorium, both cosmonauts without stress completed the three stage load (450 kgm/min X 3 min + 600 kgm/min X 3 min + 750 kgm/min X 3 min). Here their reactions to physical load were fully recovered to the preflight level.

The temporary functional character with complete recovery in the readaptation period was common for the changes in reaction of the cardiorespiratory system in all four cosmonauts. No disturbance of cardiac rhythm or symptoms of myocardium ischemia was observed in any of them. At the same time, one can note certain differences in their reaction which could depend on the peculiarities of flight and the prophylactic measures for detraining.

One can consider that with an increase in duration of the flight made, the intensity of functioning of the cardiorespiratory system became larger. For instance, the difference in frequency of cardiac contractions, in comparison with the preflight, were: in the CC-I + 5, in the FE-I + 10, in the CC-II + 13, in the FE-II + 17 stroke/min. The characteristic that the increase in intensity of cardiac activity in crew members of the second expedition was observed primarily in a state of rest deserves attention. For instance, the cardiac load index in the CC-II increased by 44%, and in the FE-II by 75%. At the same /124
time, as in the members of the crew of the first expedition, this index at rest was close to the preflight value. Consequently, the increase in intensity of cardiac activity appeared primarily as a change in regulation in the state of rest and could not be be considered as a sign of worsening of the contractile capability of the heart. We observed similar changes earlier in persons who had undergone long term bed rest [48].

According to the majority of indices of reactions of the cardiorespiratory system of the CC-I, CC-II and FE-II, they were very close and could relate to a single class of conditions. This can be characterized as a phenomenon of detraining for conditions of Earth's gravity, and restructuring of regulation. Only in the FE-I were there signs of detraining for physical load which consisted of a decrease in minute volume of blood circulation and oxygen requirement. If one correlates the difference mentioned with the report by the cosmonauts on the prophylactic physical exercises completed in space, then one can consider that it is close to the individual optimum for the CC-I, CC-II and FE-II. And only for the FE-I, it apparently was inadequate. On the whole there is a basis for considering that the system used for prevention of detraining facilitated an adequate decrease in tolerance of the cardiorespiratory system to physical load. The reactions to physical load of the crew members of the expedition on the Salyut-6 orbital station did not differ significantly from that of crew members on the Salyut-4 orbital station which completed a 63-day flight. This makes it possible to make an evaluation of test results of physical load conducted after the preceding flights more precise. The cause of the less favorable reactions to physical load after a 30-day flight, in comparison with a 63-day, apparently was not so much the incompleteness of adaptation reactions in the 30-day flight as was assumed earlier [49] as much as it was the increase in prophylactic measures during flight of each long term expedition made subsequently. /125

Thus, the results obtained of the study give evidence of the possibility of effective prophylaxis of detraining of the cardiorespiratory system to physical load in long term space flight. At the same time, an increase in intensity of cardiac activity with an increase in duration of flight indicates the necessity for improving methods of prophylactic physical exercises, providing protection of regulatory mechanisms during exercises from overload by increasing the central volume of blood. It is obvious that such improvement in methods of physical exercise like the systemization of their completion makes it possible to improve long-term space flights even more.

CERTAIN INDICES OF THE CARDIORESPIRATORY SYSTEM IN THE THIRD MINUTE OF PHYSICAL LOAD OF 600 kgm/min A MONTH BEFORE AND A WEEK AFTER FLIGHT ON THE SALYUT-6 ORBITAL STATION.

Indices	Time of the Study	96-Day Flight				140-Day Flight			
		Commander		Flight Engineer		Commander		Flight Engineer	
		Background	Load	Background	Load	Background	Load	Background	Load
Frequency of cardiac contractions. stroke/min	Before	75	II4	58	I09	64	I05	58	I03
	After	80	II9	66	II9	82	II8	86	I20
Period of ejection, ms	Before	253	220	283	235	26I	230	27I	220
	After	240	200	255	I70	250	207	245	I70
Arterial pressure, systolic, mm Hg	Before	I40	I70	I35	I40	II5	I50	II0	I60
	After	I40	I80	I20	I65	I30	I60	I30	I80
The same, diastolic	Before	70	95	75	90	70	90	60	75
	After	75	90	80	80	85	95	70	90
Cardiac load index, conv. unit	Before	I05	I94	78	I53	74	I58	64	I65
	After	II2	2I4	79	I96	I07	I89	II2	2I6
Oxygen requirement, mℓ/min	Before	254	I206	238	I445	297	I350	3I3	I22I
	After	264	I209	254	I335	296	I349	3I3	I320
Oxygen pulse, mℓ/stroke	Before	3,4	I0,6	4,I	I3,3	4,6	I2,8	5,4	II,9
	After	3,3	I0,2	3,8	II,2	3,6	11,4	3,6	II,0
Cardiac index, mℓ/min/m²	Before	2740	7790	2930	8760	–	–	–	–
	After	2630	7540	2560	8090	–	–	–	–

/126

2.3. Echocardiographic Examination /127

Echocardiography was completed according to the generally used method. Images of the structure of the heart at the level of the valves of the aorta, the mitral valve and the cord of the mitral valve (cavity of the left ventricle) were recorded in images.

Studies were made in preflight and postflight periods at rest and during functional tests, with measured physical load (MPL) on the bicycle ergometer, a passive postural test and test with negative pressure on the lower half of the body (LBNP).

A number of indices which characterize the dimensions and functions of the left ventricle were evaluated by an echocardiograph method: end systolic volume of the left ventricle (ESV), end diastolic volume of the left ventricle (EDV), stroke ejection (SE), fraction of ejection (FE), diameter of the left auricle (DLA), thickness of the myocardium of the rear wall of the left ventricle (TMD).

The echocardiographic study during functional tests was made as a component part of a complex study of the cosmonauts.

The state of the central hemodynamics preflight was evaluated according to the results of echocardiographic study at rest and when conducting measured physical load on a bicycle ergometer, gradually increasing to submaximum value. Changes in the indices of central hemodynamics when conducting bicycle ergometer tests are presented in Table 1.

In all of the cosmonauts during MPL one observed an increase in stroke ejection in relation to the state of rest, mainly due to a decrease in ESV of the left ventricle (Table 1). The degree of increase was different with variations from 15% (in the flight engineer on the second expedition -- FE-II) to 80% (in the commander of the first crew--CC-I). Then, one observes a significant increase in the indices of contractile capability of the myocardium, in frequency of FE, which as a whole was reevaluated as evidence of a good functional state of the myocardium. The indices of the central and total hemodynamics and contractile capability of the myocardium in the cosmonauts at rest and under load corresponded to the physiological age standard [8] and in the CC-I and CC-II it even exceeded it.

According to the results of postflight echocardiographic examination, a tendency was noted toward a decrease in the state of rest of the volumes of the left ventricle cavity (primarily EDV) and stroke ejection which was observed during the first few days after landing. No changes in the thickness of the myocardium of the rear wall of the left ventricle were recorded. One noted a certain increase in dimensions of the left auricle (Table 2).

As is seen from the Table, in the first days of the postflight period the EDV in the cosmonauts was decreased by 20-30% in relation to the preflight value, the decrease in stroke ejection amounted to 6-10%. The decrease in these indices in the FE-1 was somewhat more marked, respectively, by 40 and 35%.

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TABLE 1

CHANGE IN THE BASIC HEMODYNAMIC INDICES IN COSMONAUTS OF THE I AND II MAIN EXPEDITIONS ON THE SALYUT-6 STATION WITH A TEST WITH MEASURED PHYSICAL LOAD IN THE PREFLIGHT PERIOD

		Indices		Initial State	Submaximum Load
Expedition I	CC-I	ESV	cm^3	51	35
		EDV	cm^3	124	167
		SE	cm^3	73	132
		EF	%	59	79
	FE-I	ESV	cm^3	38	22
		EDV	cm^3	113	118
		SE	cm^3	75	96
		EF	%	66	81
Expedition II	CC-II	ESV	cm^3	70	25
		EDV	cm^3	141	132
		SE	cm^3	71	107
		EF	%	51	81
	FE-II	ESV	cm^3	58	38
		EDV	cm^3	124	113
		SE	cm^3	66	75
		EF	%	53	66

Conventional symbols, see text.

TABLE 2 /130

CHANGES OF HEMODYNAMIC INDICES IN THE STATE OF REST DURING THE READAPTATION PERIOD

	Indices		Pre-flight	Postflight		
				Day 1	Day 5	Day 10
Expedition I	ESV	cm^3	5I	4I	38	32
	EDV	cm^3	I24	II3	II8	II8
	SE	cm^3	73	64	80	86
	DLA	cm	2,3	2,6	2,3	2,3
	ESV	cm^3	38	20	35	4I
	EDV	cm^3	II3	66	I08	II8
	SE	cm^3	75	46	73	77
	DLA	cm	2,0	3,0	2,8	2,8
Expedition II	ESV	cm^3	70	30	4I	-
	EDV	cm^3	I4I	92	I30	-
	SE	cm^3	7I	62	89	-
	DLA	cm	2,3	2,4	2,4	-
	ESV	cm^3	58	35	4I	-
	EDV	cm^3	I24	97	I24	-
	SE	cm^3	66	62	83	-
	DLA	cm	2,4	2,5	2,4	-

Conventional symbols, see text.

In the crew who had completed the 96-day flight, basically, the values of the indices of central hemodynamics basically recovered by day 10 after landing. Nevertheless, in the flight engineer in whom one observed greater changes in the first days, on day 10, the left auricle remained increased and echocardiographic studies were repeated on days 30 and 70. At this time, the indices of central hemodynamics in him were fully stabilized and the value of the left auricle corresponded to the preflight. /129

In the second crew, even after 5 days of the readaptation period the values of the hemodynamic indices reached the preflight values and therefore further echocardiographic observation was not made.

In the first days after landing, a passive posture test was conducted on both crews according to the clinical and physiologcal examination program; the following method was used for these examinations: /131

-- a horizontal position for 30 minutes;

-- an orthostatic position (+70°) for 10 minutes;

-- a horizontal position for 6 minutes;

-- an anti-orthostatic position -15° -- 6 minutes,
-30° -- 6 minutes,
-45° -- 2 minutes;

-- a horizontal position for 10 minutes.

The echocardiogram was recorded in the last minute of each stage of the study. The data obtained are presented in Table 3.

A decrease in EDV and SE and also DLA in an orthostatic position was characteristic for all the examinations. In the anti-orthostatic position, these indices were increased. The ejection fraction hardly changed at all during the tests and only in the flight engineer of the first expedition did one observe a certain decrease of SE, particularly in the orthostatic position. One should note that in crew who had completed the 96-day flight, during the postural test on the first days after landing, changes in hemodynamics were more marked than in the second crew after a 140-day flight. For instance, in the commander and flight engineer of the first expedition, the SE in the orthostatic position decreased, respectively, by 22 to 39%, the EDV -- by 32 and 12%. When examining the second crew, one noted a decrease in SE in the CC-II by 8%, in the FE-II -- by 14%; the EDV decreased in the ortho-position, respectively, by 14 and 9% from the initial, respectively. With repetition of the postural test in the first crew in the 5 days of the postflight period, the hemodynamic reaction to the orthostatic position was less marked. According to the data of the study of the intracardiac hemodynamics by a method of echocardiography during a passive postural test, a printout was obtained showing the hemodynamic reaction to the orthostatic effect in the first days

TABLE 3

THE CHANGES OF HEMODYNAMICS DURING A PASSIVE POSTURAL TEST IN THE POSTFLIGHT PERIOD

	Indices		Horiz. Posit.	Ortho-Posit.	Hor. Pos.	Anti-ortho. Pos.			Horiz. Posit.
			0°	+70°	0°	-15°	-30°	-45°	0°
Expedition I	ESV	CM^3	62	35	44	4I	5I	-	47
	EDV	CM^3	I30	88	I30	I30	I35	-	II8
	SE	CM^3	68	53	86	89	84	-	7I
	EF	%	52	60	66	68	62	-	60
	DLA	CM	2,6	I,8	2,2	2,7	2,8	3,0	2,6
	ESV	CM^3	20	30	35	30	-	-	-
	EDV	CM^3	66	58	74	66	-	-	-
	SE	CM^3	46	28	39	36	-	-	-
	EF	%	70	48	53	54	-	-	-
	DLA	CM	3,0	-	-	-	-	-	-
Expedition II	ESV	CM^3	30	22	32	47	47	58	-
	EDV	CM^3	92	79	88	II8	I30	I30	-
	SE	CM^3	62	57	56	7I	83	72	-
	EF	%	67	72	64	60	64	56	-
	DLA	CM	2,4	2,0	2,3	2,5	3,0	2,9	-
	ESV	CM^3	35	35	4I	-	4I	38	27
	EDV	CM^3	97	88	97	-	II3	II3	74
	SE	CM^3	62	53	56	-	72	75	47
	EF	%	64	60	58	-	64	66	64
	DLA	CM	2,5	-	2,3	2,5	2,5	-	2,2

Notation: In cases when it was impossible to obtain a satisfactory recording of the echocardiograms, blanks are left in the Table.

after landing was more favorable in the second crew in comparison with the first in spite of the fact that the second crew had completed a longer flight. /133

The changes in central hemodynamics during the test with the creation of LBNP was similar to observations during the orthostatic test -- a decrease in EDV, SE, DLA without changes in indices of contractile capability of the myocardium.

Changes in the intracardiac volumes and the SE during the LBNP have the same aspect as during an orthostatic effect but less pronounced (Table 4).

Thus, the use of echocardiography for studying hemodynamics during functional tests makes it possible to discover certain principles and mechanisms of hemodynamic reactions whose study by other noninvasive methods is impossible. The results of a long-term stay in a state of weightlessness is a decrease in the diastolic and stroke volume of the left ventricles and an average reversible decrease in the functional state of the cardiovascular system.

The echocardiographic examination of the two main crews from the Salyut-6 orbital station showed that a decrease in central hemodynamics was less pronounced and recovered more rapidly in the second crew in comparison with the first.

TABLE 4 /134

CHANGES IN HEMODYNAMICS DURING A TEST CREATING LBNP, IN THE POSTFLIGHT PERIOD

		Indices		Initial State	Degree of Negative Pressure	
					-25 mm Hg	-35 mm Hg
Expedition I	CC-I	ESV	cm^3	5I	47	4I
		EDV	cm^3	I24	II3	I02
		SE	cm^3	73	66	6I
		EF	%	59	58	60
	FE-I	ESV	cm^3	22	I5	I8
		EDV	cm^3	66	58	62
		SE	cm^3	44	44	44
		EF	%	67	75	7I
Expedition II	CC-II	ESV	cm^3	4I	-	47
		EDV	cm^3	I30	-	II8
		SE	cm^3	89	-	7I
		EF	%	68	-	60
	FE-II	ESV	cm^3	4I	35	27
		EDV	cm^3	I24	97	97
		SE	cm^3	83	62	70
		EF	%	67	64	72

2.4. Results of Vectorelectrocardiographic Examination in Long-Term Space Flights on the Salyut-6 and Soyuz Orbital Complex. /135

Method

Recordings of the EKG at the 12 usual contact points was conducted in flight using a Polinom-2M apparatus with transmission by telemetric channel to Earth, and before and after flight on the Mingograf apparatus. The electrodes were fixed on the extremities using rubber cuffs and thoracic electrodes using a band.

The Lamb method was used for conducting a spatial vector analysis [50], modified appropriately for the purpose of the study [51].

Calculation of the angle of deflection of the projection of the spatial vector on the horizontal plane from the X axis (angle H) along the orthogonal spherical contact, Y_2 and Y_6, was made in accordance with this method [52,53,54] and based on the value of this angle and the value of the coordinates of X at lead 1, the coordinates of Y and the integral vectors of depolarization and repolarization of the myocardium of the ventricles were calculated.

The use of the principle described of a spatial quantitative analysis was corrected in such a way that the evaluation was subject to the dynamics of valuesof direction of the vectors and not their absolute values which underwent local effects constitutional peculiarities and other moments.

The following indices were evaluated with a quantitative spatial analysis: the values of integral vectors of depolarization and repolarization ($\overline{M}$QRS $\overline{M}$T); the angles which define the position of the projection of vectors in a frontal plane (angle α) and in a horizontal plane (angle H).

Vector analysis of EKGs recorded in flight was made only in the frontal plane (the values of the projections of vectors on this plane $\overline{M}$QRS and $\overline{M}$T and angles which characterize their position), inasmuch as, in these conditions the thoracic bipolar leads CR were recorded. Taking into account that frequency characteristics of the equipment used in flight and during ground observation were different, the values of vector indices in flight were not compared with the preflight data and only the dynamics was considered of these indices for the extent of the flight. /136

Results and their Consideration

Bioelectrical activity of the myocardium preflight in all four cosmonauts was without significant deviations from normal. For the entire extent of the flight, in both crews, the rhythm of cardiac contractions was sinusal, whereas under certain examinations of all cosmonauts (except the FE-II) a sinus arrhythmia was noted. The time indices of the EKG during and after flight did not go beyond the limits of the physiological standard in preflight variations; only in the

CC-I on day 70 was an increase noted in the auricle ventricle conductivity by 0.03 s in comparison with the preflight data. Recovery of this index occurred on day 18 of the postflight period. The shape of the electrocardiogram during and after flight, as a rule, remained without significant changes. However, in the CC-I lead III on day 5 postflight, the T wave became slightly negative (preflight and inflight it was low positive or isoelectric). The ratio of the projection of vectors of depolarization and repolarization of the myocardium of the ventricles and their condition on the frontal plane changed individually in all cosmonauts. The values of the vectors in flight, due to deviations in operation of the calibrator in certain studies were not determined. /138

In the postflight period, the most general change was a decrease in the value of the integral vector of repolarization. This index on the day of landing was sharply decreased in all four cosmonauts (Figure 1). Later on it increased, however in three cosmonauts during a month of study it did not reach the mean preflight level. Moreover in the CC-I, the vector $\overline{MT}$ even after 24 hours postflight was significantly increased, exceeding the upper preflight level.

A decrease in the integral vector $\overline{MT}$ in the postflight period can depend on the phenomena of vegetative imbalance which has developed and also possibly, reflects the presence of metabolic changes in the myocardium. After a long stay in weightlessness, the effect of Earth's force of gravity is a fairly strong stimulant causing a sudden increase (in comparison with weightlessness) in the flow of the afferent pulsation with mechanoreceptors which can activate the adrenergic system. As a result, obviously, a transient imbalance in the ratio of the tonus of the sympathetic and parasympathetic systems develops, occurring on a background of a strong stress effect in the descent section and asthenia caused by a long stay in flight. According to the data of [55], the adrenergic effects on a background of previous stress or asthenia, as was observed in hypokinesia conditions, caused a decrease in the voltage of the T wave and, consequently, a decrease in the T vector.

The research by R. A. Tigranyan with coworkers [56] showed postflight in the MC-I a high level generation of total 17-HCC [hydroxycorticosteroid] from the urine with simultaneous increase in free 17-HCC which can indicate a state of stress and facilitate a breakdown in the process of repolarization. This affects the possibility of metabolic changes in the myocardium and indicates results of biochemical studies after a number of long term space flights [57,58], in particular, a decrease in the content of potassium in the organism and an increase in the content of certain cardiac enzymes in the blood. However, the picture observed of EKG changes precludes connecting them with changes in the content of these and other electrolytes in the organism in an actual case. /139

The value of the vector of depolarization of the myocardium of the ventricles usually does not undergo significant changes postflight and only in the CC-I, beginning with a study on the day of landing and up to the 33rd day, exceeded as a rule the maximum preflight values of this index (Figure 1). The absence of marked changes in the value of the integral vector QRS (at least the absence of a decrease) indicates

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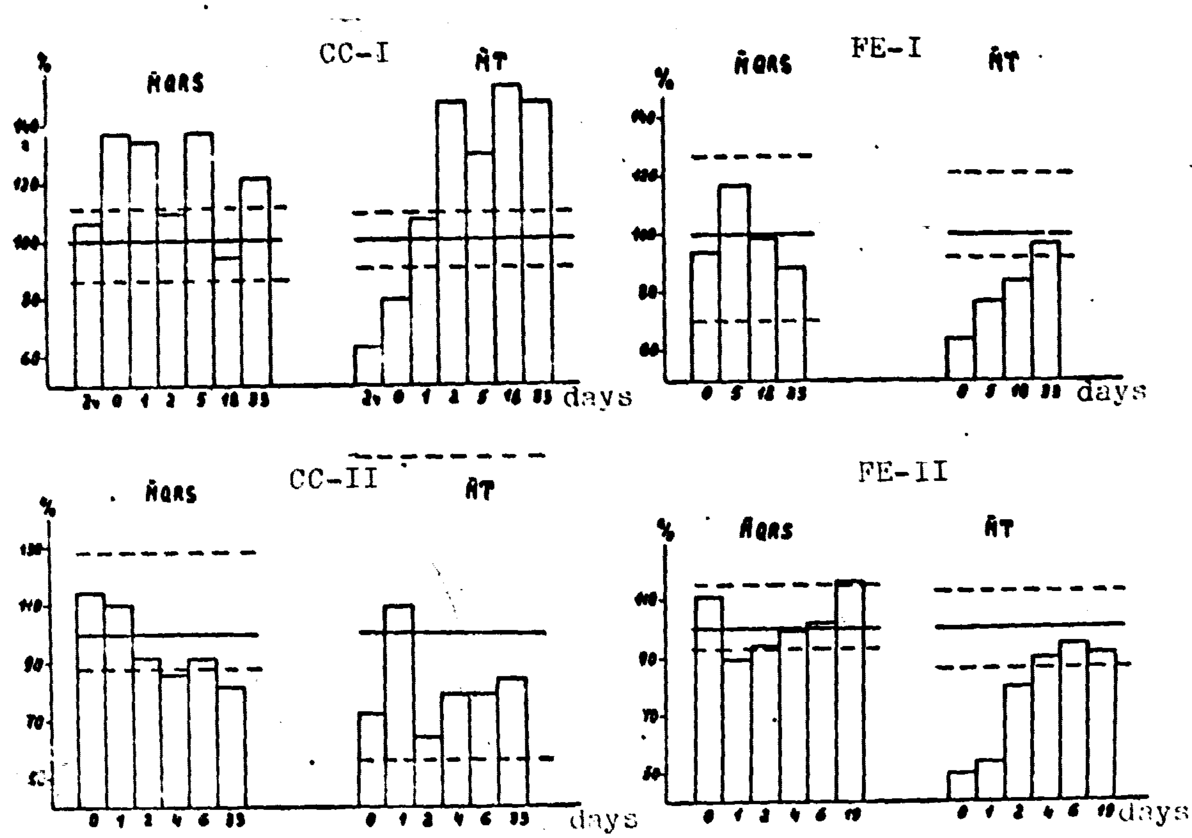

Figure 1. Dynamics of the value of spatial integral vectors of depolarization ($\overline{M}$QRS) and repolarization ($\overline{M}$T) in the cosmonauts postflight.
Symbols:
CC-I and FE-I - commander and flight engineer of the first main crew;
CC-II and FE-II - commander and flight engineer of the second main crew;
- - - - - - - - limits of variation of the index in the preflight period;
__________ - mean value of the index preflight.

that under the effect of flight conditions, apparently, no significant dysfunctions of the process of depolarization were detected. This possibly is due to the fact that during flight systematic physical training was carried out in different volumes. Moreover, the following discoveries by our coworkers I. V. Alferova and V. F. Turchaninova during flights, the increase in cardiac ejection (rheographic method), the appearance of symptoms of load of the heart by volume and an increase in its suction function (according to the data of phase analysis) involve, apparently, transfer of the fluid in the cranial direction and a decrease in load on the muscle system resulting in a decrease in activity of the "peripheral muscle cores" [59] and can be considered as adaptive reactions facilitating maintenance of the cardiac muscle in good condition. /139

A significant change in position of the M̄OR5 projection on the frontal plane was observed only in the CC-II in the form of a decrease in the α angle QRS at 15-24° in comparison with the preflight data (Figure 2). A decrease in this index lasted for a month.

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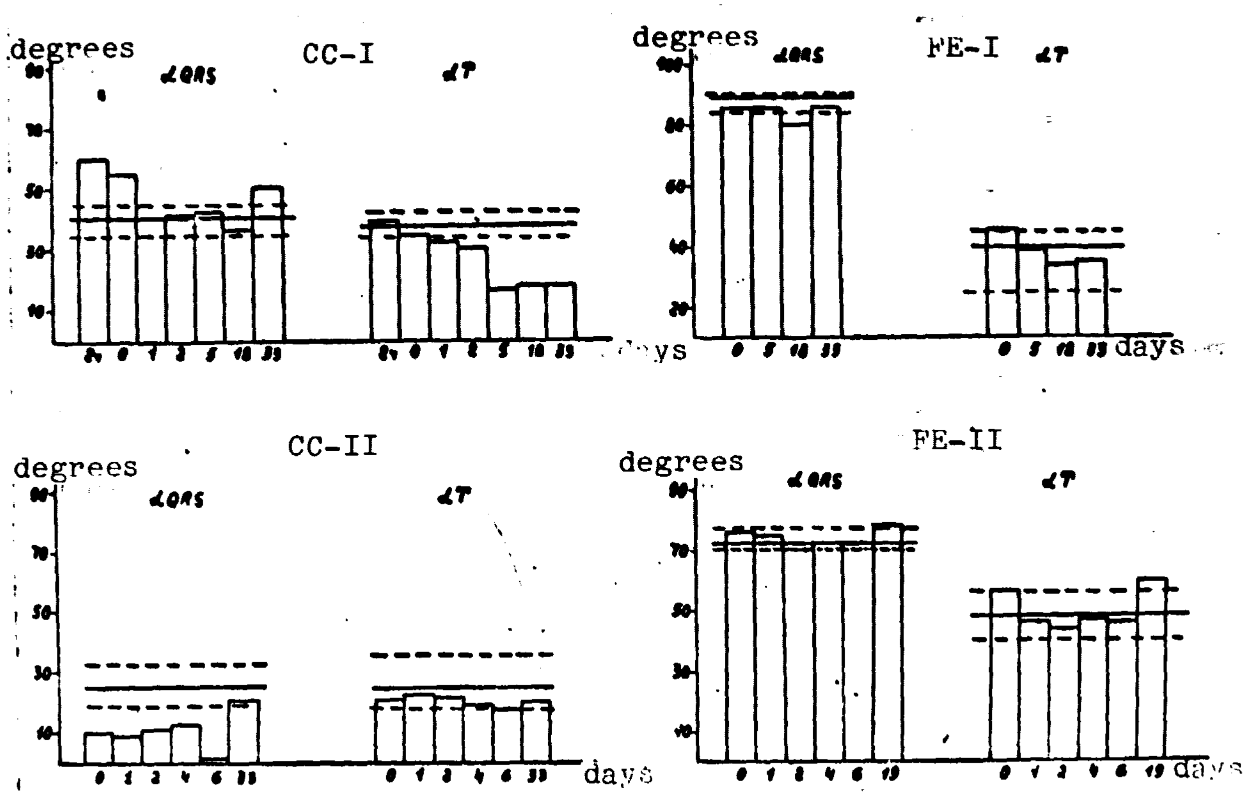

Figure 2. Dynamics of the value of angle α QRS and α T, which define the orientation of projections of corresponding integral vectors in the frontal plane.
Symbols are the same as in Figure 1.

The angle HQRS in all cosmonauts preflight and postlight was negative and in the postflight period, as a rule, it decreased in three cosmonauts but in the CC-I it was decreased only on days 2 and 18 (Figure 3). /141

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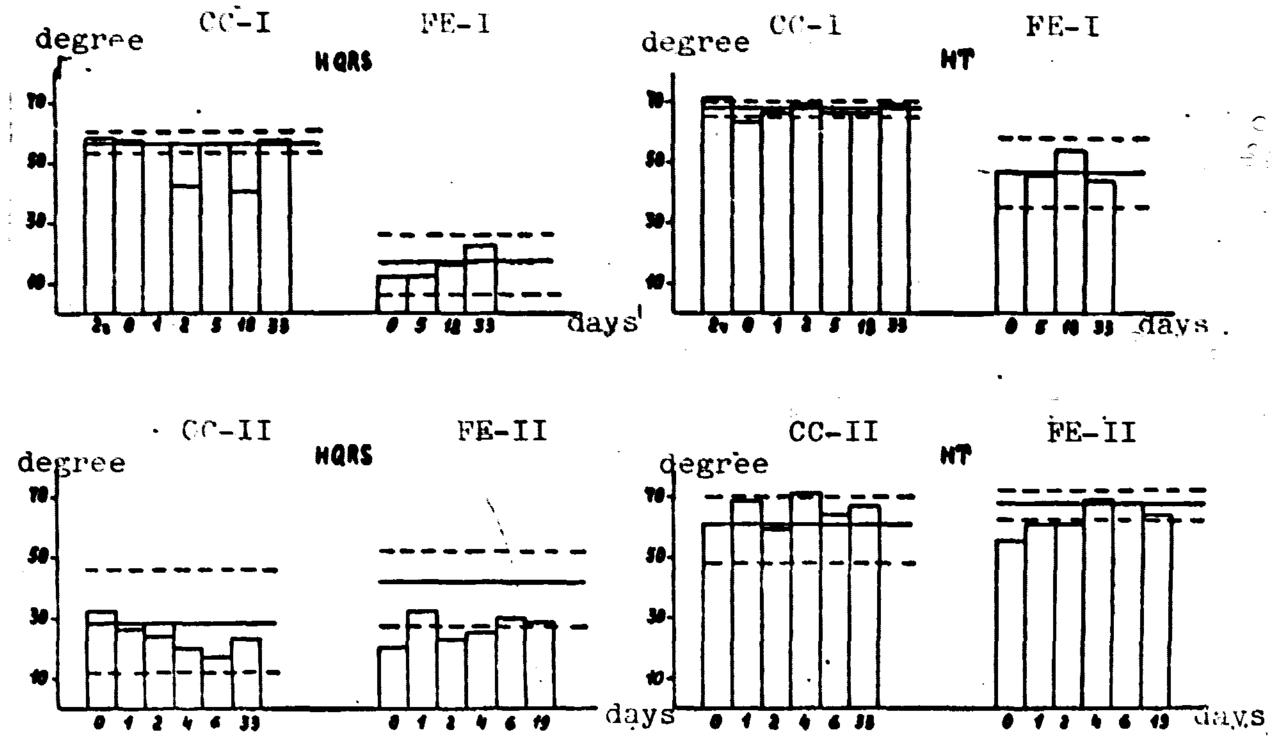

Figure 3. Dynamics of the values of angles HQRS and HT which define orientation of the projection of appropriate physical vectors in a horizontal plane. The negative values of HQRS indicate that the vector is oriented from behind the frontal plane.
Symbols are the same as in Figure 1.

Thus, the most significant change with a marked decrease in all four cosmonauts of the value of the integral vector of repolarization on the day of landing, which was not recovered in three of them after a month at the postflight examination and also a tendency toward a shift of integral QRS vector forward in three of the cosmonauts in the postflight period. As a whole, the studies made indicated that the changes in bioelectric activity in flight were not clinically significant, were not related to hemodynamics and the state of health of the crews. /141

2.5. Results of Dynamic Electrocardiographic Study. /143

Method of Study.

A 34 hour continuous recording of electrocardiograms at the DS contact point using a portable cardiomonitor was carried out on the cosmonauts V. V. Kovalënok and A. S. Ivanchenkov in the pre- and post-flight period and at days 120-122 during the 140-day flight on the orbital Salyut-6 station. For a comparative evaluation of the recordings obtained in the preflight examinations, dynamic electrocardiography was conducted on 10 cosmonauts who had completed space flights in the last 2 years. The electrocardiograms obtained, besides the traditional analysis (discovery of disturbances in rhythm, control of the ST segment position, study of the amplitude of waves R and T, etc.) were subjected to a special mathematical analysis.

In each of the numbered files from the 100 RR-intervals, a number of different statistical indices were determined. In a physiological interpretation of the mathematical indices used in the work of cardiac rhythm and their mean 24-hour values according to the data of preflight examinations of the group of cosmonauts are presented in Table 1. The proposed physiological interpretation comes from the present level of knowledge of mechanisms of regulation of cardiac rhythm and the existing intrinsic bibliographic data [60,61,62]. The program of mathematical analysis of cardiac rhythm was realized on an EVM [elektronnaya vychislitel'naya mashina, electronic computer] type YeS-1030. Figure 1 shows a diagram of determination of the mathematical indices used according to the data of histographic and spectral analysis of numerical files of the RR-intervals. In this work, the average 24-hour values of mathematical indices are presented as well as the amplitude of 24-hour variations and indices of synchronization of different indices in the 24-hour cycle. A correlation analysis was used for /146 evaluating the degree of synchronization. Paired coefficients of mutual correlation between series of hourly values of the indices were calculated. Also a complex index of synchronization of the processes was used in the form of the total of paired coefficients of correlation for 10 indices (the absolute values of the coefficients of correlation were added together).

Results of the Studies and Their Discussion.

In the preflight period, certain peculiarities of the EKG were not apparent except for a certain increase in the T wave and a shift by 1.5 m upward of the ST interval in A. S. Ivanchenkov during sleep; this indicates a pronounced increase in the tonus of the parasympathetic section of the vegetative nervous system. On days 120-121 of flight, in V. V. Kovalënok, one noted a certain decrease in the T wave and an increase in the systolic index by 6-12%. In A. S. Ivanchenkov, on days 121-122 of flight, an unfavorable EKG reaction was apparent during daily physical training (lengthening of the recovery period for pulse, a sickle shaped ascending shift in the ST interval) and at certain hours variation amplitude of the R deflection with a weakly expressed

TABLE 1 /144

A PHYSIOLOGICAL INTERPRETATION OF CERTAIN MATHEMATICAL INDICES OF CARDIAC RHYTHM AND THEIR MEAN 24-HOUR VALUES ACCORDING TO THE DATA OF DYNAMIC ELETROCARDIOGRAPHY

Indices	Physiological Interpretation	M±m
M - universal mean	Mean level of functioning of the cardio-vascular system.	0,87±0,00I s
σ - mean quadratic deviation (MQE)	Total effect of regulation of cardiac rhythm by autonomous and central contours of control.	0,065±0,00I
AMo - amplitude of the mode	Index of stabilizing effect of the central contour of control on the autonomous activity of the sympathetic section of the vegetative nervous system.	4I,2±I,2%
SI - stress index	Index of activity of the central contour of control, activity of the sympathetic section of the vegetative nervous system.	I24,9±4,I
ΔX - varied peak-to-peak value	Index of activity of the autonomous contour of control, activity of the parasympathetic section of the vegetative nervous system.	0,28±0,004 s
Sd - power of the respiratory waves	Index of the activity of the autonomous contour of control, activity of the centers of the vagus nerve and the respiratory center.	0,I6±0,002
So - Power of the low-velocity waves	Total activity of different levels of central regulation of cardiac rhythm.	0,033±0,0002

sinusal arrhythmia. The changes apparent in the EKG, apparently, can /146
be evaluated as preclinical signs of stress on the myocardium.

After a four month stay in weightlessness conditions, the average 24-hour values of the universal mean for duration of the RR interval (value of reverse of frequency of pulse) proved to have decreased only in V. V. Kovalënok (Table 2). The amplitude of the mode was increased (statistically verified) only in A. S. Ivanchenkov. The variation peak-to-peak value and mean quadratic deviation in both cosmonauts decreased but the stress index increased (in all cases statistically verified). According to the data of spectral analysis, the power of the respiratory waves was unchanged and the power of the low-frequency waves was statis- /148
tically proven to be decreased only in A. S. Ivanchenkov. The amplitude of 24-hour variations in mean values of duration of cardiointervals was decreased in V. V. Kovalënok. The changes in amplitude of 24-hour variations of MQE, SI and ΔX were unitypical in both cosmonauts: the SI

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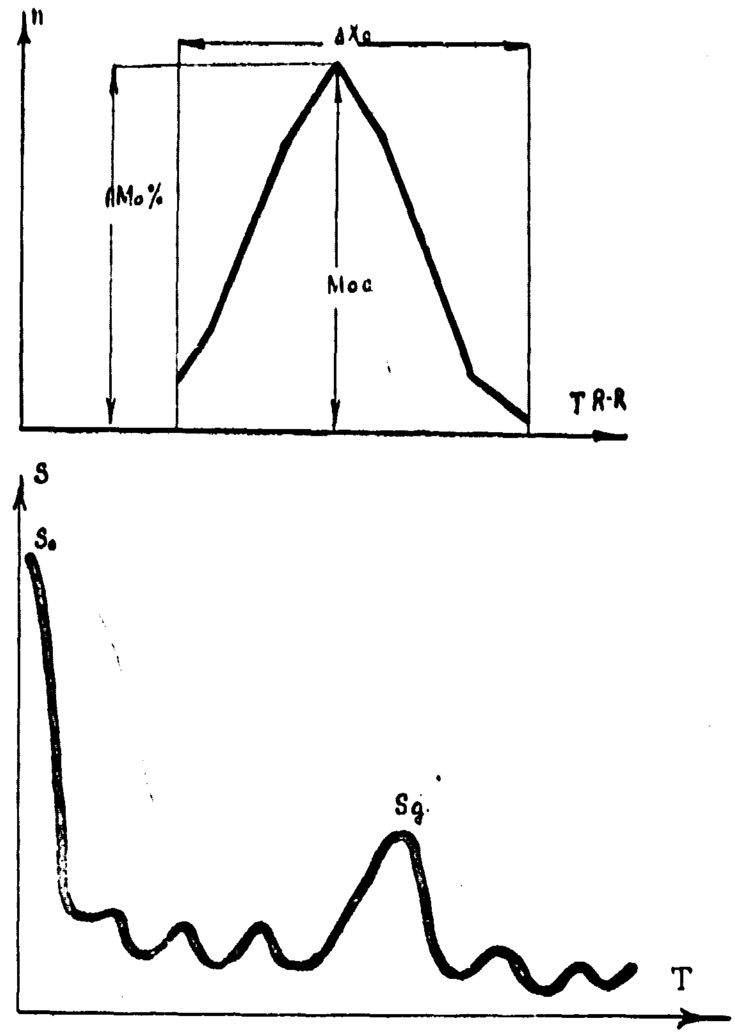

Figure 1. Diagram for determining mathematical indices of the cardiac rhythm with histographic (upward) and spectral (downward) analysis of dynamic series of RR-intervals.

amplitude was increased, the MQE amplitude and ΔX were decreased. /148
Synchronization of the mathematical indices in a 24-hour cycle according to this index of the total of correlation coefficients in flight decreased as a whole. However, there were individual differences in the correlation ratio between different parameters. In V. V. Kovalënok, synchronization of the M-MQE and S_t-S_d decreased. In A. S. Ivanchenkov, these indices were unchanged. When considering the results of mathematical analysis of cardiac rhythm one should note that changes common for both cosmonauts exist as well as individual peculiarities. The unitypical are such shifts as a decrease in MQE and ΔX, an increase of SI and AMo, a decrease in the total coefficient of correlation. Changes in amplitude of 24-hour variations of MQE,

TABLE 2

RESULTS OF MATHEMATICAL ANALYSIS OF CARDIAC RHYTHM IN V. V. KOVALËNOK AND A. S. IVANCHENKOV DURING FLIGHT ON THE ORBITAL SALYUT-6 STATION

Indices	V. V. KOVALENOK		A. S. IVANCHENKOV	
	Preflight	Days 120-121 of flight	Preflight	Days 120-121 of flight
Average 24-hour values				
M/s/	0,88±0,03	0,66±0,0I	I,02±0,04	0,94±0,04
MQE/s/	0,6I±0,00I	0,046±0,003	0,84±0,0I2	0,042±0,004
AMo/%/	43,3±2,7	50,I±4,I	36,7±2,8	60,4±4,I
ΔX % /s/	0,28±0,03	0,2I±0,02	0,34±0,03	0,I9±0,0I
SI/conv. unit	I29±22	260±53	94±2I	250±60
St	0,I6±0,02	0,I3±0,02	0,2I±0,04	0,I2±0,02
Sd	0,03±0,006	0,03±0,003	0,03±0,006	0,03±0,004
Synchronization in the 24-hour cycle				
M-MQE	0,44	0,23	0,45	0,42
SI-ΔX	-0,66	-0,78	-0,67	-0,65
So-Sd	-0,46	-0,I0	-0,50	-0,52
Total	43	26	58	22
Amplitude of 24-hour variation				
M	0,63	0,28	0,76	0,7I
MQE	0,I2	0,06	0,22	0,08
ΔX	0,40	0,20	0,60	0,35
SI	299	III8	4I3	I476

ΔX and SI were unitypical. The indicated changes are evidence of an /148
increase of activity of the sympathetic section of the vegetative nervous system, an increase in centralization of control of the cardiac rhythm. Certain peculiarities of the reaction were apparent in A. S. Ivanchenkov. An increase in frequency of the pulse was noted in him (a decrease of M) as in V. V. Kovalënok, the amplitude of 24-hour variations of average duration of the cardiac cycle was retained whereas in V. V Kovalënok it decreased. The impression is created that besides an increase in the tonus of the sympathetic section of the vegetative nervous system in A. S. Ivanchenkov, higher levels of control were activated which provide maintaining 24-hour variations in pulse frequency and retaining mean values at preflight limits. The presence of statistically proven decreases in power of the low-velocity wave in A. S. Ivanchenkov in flight is evidence for this hypothesis /149
inasmuch as this means that there is centralization of control in relation to this shape of control which shows the low-velocity wave which we recorded in a range (up to 40 s).

Individual peculiarities of the reaction of the circadian system of the organism to conditions of long-term space flight are visually demonstrated by graphs of 24-hour changes of M and SI in the preflight period and on days 120-122 of the flight. Preflight, in V. V. Kovalënok, a short 24-hour dynamics of the indicated indices is clear. In flight, 24-hour variations level off and nocturnal diurnal indices are not distinguished. In the evening hours, a significant increase in the stress index is observed. In A. S. Ivanchenkov, in flight, the 24-hour periodicity of both indices is retained, however, in the daytime there are marked variations in the stress index. One should note that in the postflight period, A. S. Ivanchenkov retained for a long time the phenomena of stress of the regulatory mechanisms. On days 8-9 postflight, the mean 24-hour values of SI were equal to 227 ± 24, AMo -- 49.8 ± 2.0.

As a whole, the analysis of materials of dynamic electrocardiography in crew members of the second expedition on the orbital Salyut-6 showed that a long-term stay in weightlessness conditions results in a certain restructuring of the regulatory mechanism, in particular, the control system for cardiac rhythm. After four months of flight, in the cosmonauts V. V. Kovalënok and A. S. Ivanchenkov, activation of the sympathetic section of the vegetative nervous system was observed. Moreover, characteristic individual changes were noted in other links of the control system for cardiac rhythm. In V. V. Kovalënok, the 24-hour rhythm of mathematical indices of cardiac rhythm smoothed out. In A. S. Ivanchenkov, on a background of sympaticotonic reactions, one noted activation of higher levels of con- /150
trol of cardiac rhythm. The indicated changes cannot be reevaluated as pathological. Apparently, there is a principal restructuring of the regulatory systems caused by a process of adaptation of the organism to a new condition unusual for it. This restructuring involves stress of the adaptation mechanism; the shift of vegetative homeostasis toward a predominance of activity of the sympathetic section of the vegetative nervous system is evidence of this. A further increase in the time man stays in space flight conditions requires a more thorough calculation of the "price" of adaptation of the organism to weightlessness. In this study plan, the degree of stress of the regulatory

mechanism and the levels of activation of control systems according to the data of dynamic electrocardiography take on an important prognostic value.

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PART III

STUDY OF THE MOTOR SPHERE AND THE VESTIBULAR FUNCTION

In the complex of disorders caused by a decrease in weight load, disturbance in function of the support-motor apparatus and the system of motor regulation is particularly important. The data discovered, after a number of previous long-term space flights, on the statokinetic disorders, changes in regulation of the vertical posture, decrease in weight, development of muscular atrophy, vestibular dysfunctions, are all inadequate for constructing a single hypothesis that satisfactorily explains the mechanism of change in the motor apparatus of the vestibular function. Moreover, in long-term space flights, the question of predicting and correlating these changes using a scientifically based system of prophylactic measures acquires great significance. /156

In this connection, in the 96-day and 140-day flights, continuous attention was devoted to the study of the motor sphere and the vestibular apparatus. A broad spectrum of methods was used for this including study in flight (measurement of the mass of the body and the volume of the crus) and particularly, postflight. A program of preflight and postflight studies included an evaluation of the following:

-- muscles--according to the coefficient of electromyographic effectiveness of muscular contractions;

-- the leading proprioceptor inputs: support--according to the threshold of vibration sensitivity of the support zones of the foot; muscular--according to the threshold and other indices of the curve of implication of the tendon (Achilles) reflex; vestibular--according to the intensity of the otolithic reflex, the value of the threshold sensitivity to angular acceleration, the reciprocal relationship between otolithic and semicircular canals; the spinal apparatus, in particular, the mechanism of interextremity synergy;

-- the system of control of motion--according to the data of cyclography of locomotor acts, stabilography and methods of studying the posture synergy.

The results of anthropometric studies in flight and study of the vestibular and motor apparatuses postflight are presented below.

3.1. Dynamics of Body Mass in the 140-day Flight /157

Method

In weightlessness conditions, the inertia properties of the body are used for measuring body mass. A linear unidimensional harmonic oscillator was the basis for technical realization of an instrument for measuring body mass in weightlessness. The body whose mass must be measured is attached to a spring and can move along its longitudinal axis. When shifting the body relative to the postion of equilibrium with its subsequent release, it completes oscillations whose T period is defined by the relationship: $T = 2\pi\sqrt{\frac{M}{K}}$, where K is the coefficient of elasticity of the spring and M is the mass of the body.

The formula presented is true for an absolutely solid body. Due to the fact that the human body is a mechanical system consisting of solid structures and semifluid masses, it can be approximated at low frequencies and low levels of vibration of a linear system with a finite number of degrees of freedom. The presence of resonance frequencies in the "chest cage-abdominal cavity" field (from 3 to 6 Hz) is the basis for selecting a frequency range of measurement from 0.3 to 0.5 Hz.

For increasing precision of measurement, the cosmonauts assumes a pose in which it is possible to regulate the degree of pressure on the mass meter platform. Then, the cosmonaut moves on the platform in the "lying on the stomach" position, the chin rests on an extensible insert (for fixing the head), the hands are on a lever, the feet on footboards. Using the handle located at the base of the instrument, the movable part of the instrument is tightened in a low fixed position with pressure of the fingers on the flip-flop catches; the movable part begins to oscillate in a period determined by the body mass of the person. Before measuring the mass, calibration of the instrument is accomplished as well as control of its technical state by measurement of the oscillation period of a calibrated mass (movable part of the instrument). Measurement of body mass of a person is done when holding the breath and tightening the muscles.

Results of the Study and a Discussion of Them /158

Measurement of body mass began to be done on the 4th day of flight and by the 11th day it was carried out daily. Later on, body mass was measured approximately once every 2 weeks.

On the 4th day of the flight, the equivalent value of weight obtained used the instrument for measuring body mass[1] was decreased in comparison with the preflight weight in the crew commander (CC) by 1.4 kg and in the flight engineer (FE) by 0.55 kg (Table 1, Figure 1). Later on in the CC, by the 22nd day of flight, weight loss not only had not increased but even had decreased and amounted to 0.31--1.03 kg. From the 44th day to the 59th day in-flight, one observed in the CC an increase in weight loss to 2.3--3.4 kg, and by days 63--122 the weight loss in him amounted to only 0.7--1.6 kg. The weight dynamics in the FE in-flight were different and were characterized by a progressive increase in weight loss up to the 86th day of flight. At this time, the weight of the FE was decreased by -5.4 kg. Later on, the weight loss gradually decreased and by day 122 of the flight amounted to 3.8 kg. Then, after the flight, in the CC, the weight recovered in a

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[1] Later on, for uniformity, instead of body mass, the term body weight is used.

TABLE 1. THE DYNAMICS OF BODY WEIGHT IN A 140-DAY FLIGHT OF THE SECOND EXPEDITION OF THE ORBITAL SALYUT-6 SOYUZ COMPLEX

Commander

Days of Flight	Preflight	In-flight								
		4	5	6	7	8	9	I0	II	22
Weight	84.500	83.I0	84.I9	83.98	83.60	83.86	84.40	83.47	84.II	83.93
Weight deficit		-I.40	-0.3I	-0.52	-0.90	-0.64	-0.I0	-I.03	-0.39	-0.57
		45	59	63	64	70	86	93	I02	I22
		82.20	8I.06	83.80	83.40	83.22	82.24	82.84	83.54	83.47
		-2.30	-3.44	-0.70	-I.I0	-I.28	-I.66	-I.66	-0.96	-I.03

Flight Engineer

Days of Flight	Preflight	In-flight							
		4	5	6	7	8	9	I0	II
Weight	75.500	74.95	75.32	74.4I	74.55	74.47	73.99	75.22	73.52
Weight deficit		-0.55	-0.I8	-I.09	-0.95	-I.03	-I.5I	-0.23	-I.98
		22	45	59	70	86	I02	I09	I22
		73.26	7I.85	7I.80	72.60	70.09	70.87	7I.22	7I.23
		-2.24	-3.65	-3.70	-2.90	-5.4I	-4.63	-4.28	-3.8I

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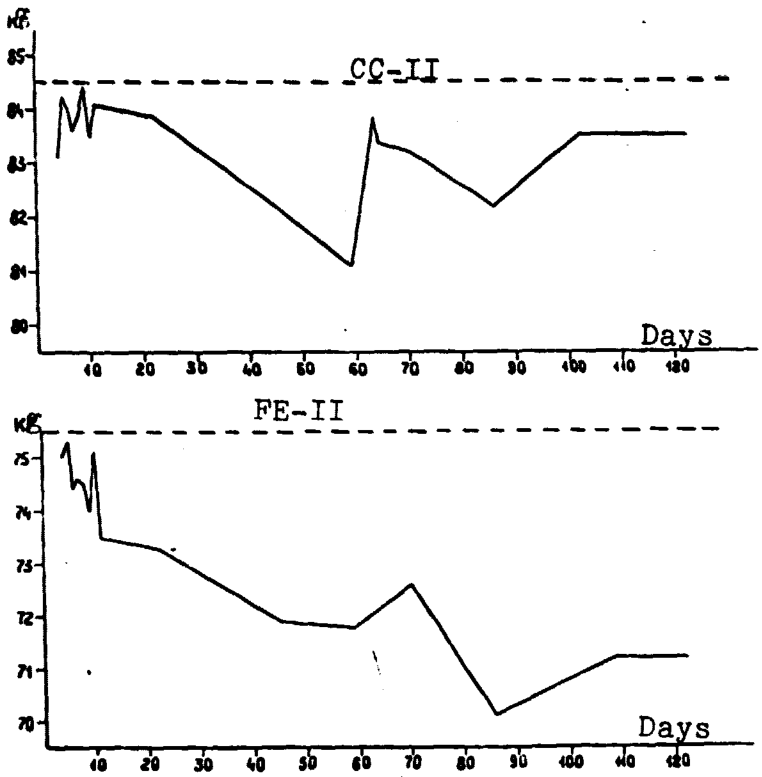

Figure 1. Dynamics of body mass of the second main crew in flight

Symbols: CC-II--Crew commander;
FE-II--Crew flight engineer;
- - - -Mean value of the index preflight;
_____ -Value of the index in flight

period of 3 days and in the FE in approximately 2 weeks. /158

During an analysis of the weight dynamics in flight conditions it is necessary to take into consideration the number of moments which, as one sees from further presentation, had a definite effect on weight. The "Excursion" operation involving work in spacesuits outside the spacecraft, was accompanied by a weight loss in the CC of 0.7 kg and in the FE of 0.85 kg. Completion of physical exercises on the equipment on board also resulted in a weight loss. Control measurement of mass before and after exercise is evidence of this; this was done on the CC on days 63 and 64 of flight and showed a decrease under the effect of physical exercises of approximately 0.6 kg. Finally, one should also take into account the role of the metabolic factor involving food intake. Data on weight dynamics in the FE from day 86 to 122 of /161
the flight shows this particularly graphically. An analysis of the situation on day 86 of flight, when weight loss in the FE amounted to 5.4 kg indicated that the FE did not fully require his daily ration of food whose calorie content was approximately 3100 kcal/24-hours, due

to a selective decrease in appetite for certain food products. Therefore, it was recommended that one use three 24-hour menus for the crew daily in order to vary the selection of food more broadly. This measure, and also delivery of products with the Progress-4 cargo spacecraft (taking into account the wishes of the crew) facilitated decreasing weight loss in the FE from 5.4 kg on day 86 to 3.8 kg on day 122.

Finally, one should also consider that the intensity and duration of physical exercises in the FE, although they were fairly high, nevertheless were lower than in the CC. This circumstance could facilitate a greater loss in muscle mass which is confirmed, in particular, by the slower weight recovery in the FE postflight.

Summarizing what has been presented, one can conclude that during flight in the CC, one did not observe a sharp relationship of weight loss to duration of the flight. The more pronounced weight loss observed in him on days 44--59 amounted to 2.3--2.4 kg and in other flight periods not more than 1.7 kg (day 86 of flight). In the FE the weight progressively decreased to the 86th day of flight (maximum at 5.4 kg) and later on, due to the measures taken to replace certain dishes in the menu, in relation to which there was a selective decrease in apetite, the weight deficit decreased. A study made on the 140-day flight of body weight made it possible to propose that the main facotrs which cause weight loss are the following:

-- redustribution of the fluid media of the organism which, in accordance with modern concepts, results in a loss of certain parts of the fluid in the organism; /162

-- periods of high physical activity;

-- inadequate compensation of metabolic loss of the food rations which can occur due to different causes;

-- varied stress effects, in particular, emotional stress in critical operations, for instance "Excursion" or descent of the spacecraft;

-- loss of muscle mass as a result of inadequate load on the muscle system as a whole and separate muscle groups separately.

3.2. Change in the Volume of the Crus In Flight

The volume of the crus was evaluated using a specially developed measuring instrument. The measuring tape placed on top of its elastic section made it possible to judge the value of the parameters of the crus at 8 levels, 3 cm from each other. On the basis of the hypothesis that segments between the measuring tapes are truncated cones, the volume of the section of the crus 24 cm long was determined as the total of 7 truncated cones.

During the flight, in the CC-I, studies were made on days 6, 41 and 91 and in the FE--on days 6, 13, 29, 41 and 91. At the same time in both cosmonauts, members of the second main crew, the volume was measured on days 4--11, 22, 82, 97, 102, 111 and 120. Moreover, just in the CC-II, on days 31, 38, 40 and 56 and in the FE-II on days 39 and 59. In all of the cosmonauts, studies were made in the background period (BP). Changes in volume (in relation to the background) were evaluated in relative (%) and absolute (cm³) values.

In the 140-day flight, the volume of the crus in both cosmonauts decreased and in the first 11 days of flight by not more than 11--13%. On days 80--100, the volume of the crus progressively decreased in the CC-II by 23.0%, in the FE-II by 19.6% and stabilized later on. In the 96-day flight, the decrease in volume of the crus did not depend on the duration of the flight and its deficit amounted in the CC-I to 17--20%, and in the FE-I to 9--16% (Figure 1) [Sic. Figure 2].

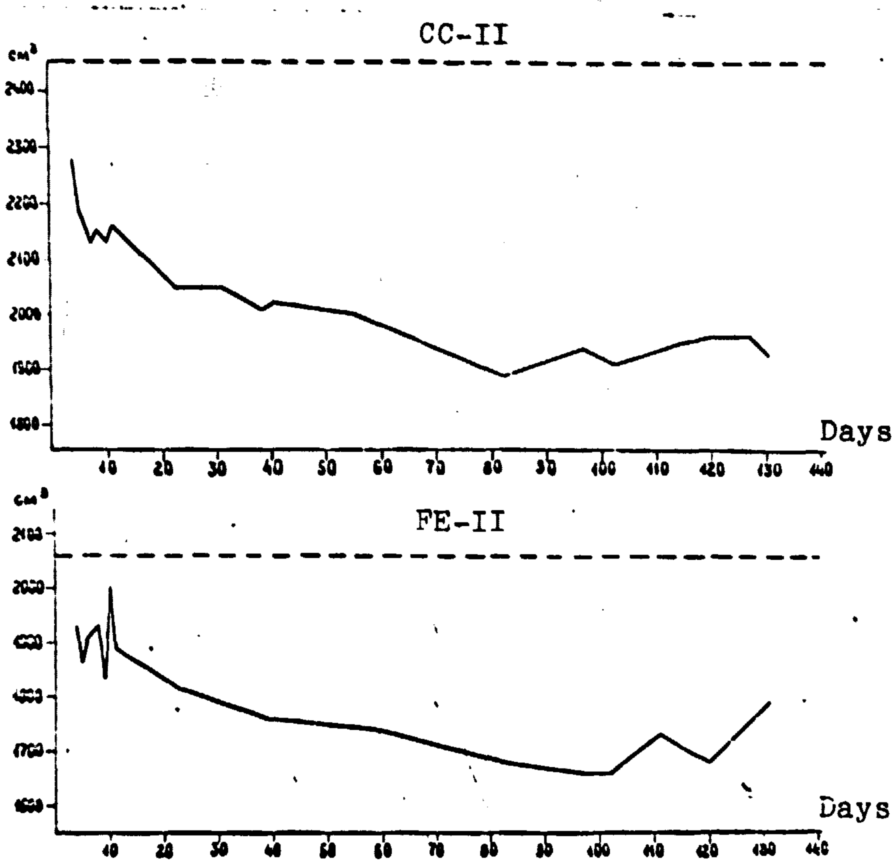

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Figure 2. Dynamics of volume of the crus in the second main crew in-flight.

Symbols: CC-II--Crew commander;
FE-II--Crew flight engineer;
- - - -Value of the index preflight;
_____- Value of the index in-flight

3.3. Study of the Motor Apparatus and the Motor Regulation System /164

Method

The "Miotest" method based on determining the electromechanical effectiveness of muscle contraction was used for evaluating the state of the muscles of the crus and femur. It is well known that the relationship between the muscle strength developed and the value of the integrated myogram has a linear character. It is also well known that when decreasing contractile properties of the muscle, amplitude of integration of the EMG when carrying out the standard force increases as a result of increase in the number of contractions of the motor units involved, the increase in frequency of their stimulation and synchronization of their activity. Starting from these suppositions, the main criterion of evaluating the functional state of the muscles studied in the Miotest method is the coefficient of electromechanical effectiveness (EMEM) which is calculated as the ratio of the value of integrated EMG to the value of standard load prescribed for the muscles of the crus by a spring pedal, and for the femur by an additional load attached to the malleolus.

The motor task when testing the state of the muscles of the crus involves completing a series of plantar flexions with small amplitude and strength. A light signals the adequacy of the amplitude; when it switches on it is the signal for the beginning motion and when it switches off indicates an adequate level of flexion. The value of load then amounts to 5 and 7 kg which at a given amplitude does not exceed 8--12% of maximum force. The motions are carried out in dynamic and static states; in the first case, a series of sequential motions is tested and in the second case, having made the flexion, this position is maintained for 15 seconds. In both cases, the EMG of the m. gastrocnemius and the m. tibialis anterior is recorded. During testing of the muscles of the femur, the test motion is bending the leg /165
at 120° (position lying down) to full straightening with subsequent holding of this position for 5--8 seconds. Inasmuch as the quantitative character of the connection between the value of the EMG and strength in test conditions changes depending on a number of factors including the initial length of the muscle, testing is done in standard conditions lying down with fixing of adjacent joints for operation of extremities.

The state of the support input of the foot was judged according to the threshold of vibration sensitivity of the support zones of the foot. As is well known, vibration stimulation is one of the most adequate and effective stimulants of the mechanoreceptors; the essence of their effect involves conversion of mechanical energy of the stimulation to a bioelectric signal. The Fater-Pacini corpuscles, highly sensitive to vibration stimulation, are concentrated in a human in the subcutaneous fat of the support zones, in the medial and lateral tactile cushions of the foot, in the field of the calcanean tuber, to a lessor degree in the medial edge of the sole and in the cushion of the large toe. At these points, the "Vibrotestr" instrument determined the threshold of vibration sensitivity at three frequencies of stimulation: low--63 Hz, average--125 Hz and high--250 Hz. In field conditions, the minimum threshold of excitation of the support receptors was detected at a frequency of 100--120 Hz and adjacent multiple values--60 Hz and 250 Hz. With damage to the receptor apparatus, the range of frequencies perceived decreased sharply.

An evaluation of the state of muscle input and mechanisms of spinal regulation involved with it was based on determining the parameters of the curve of involvement of the tendon reflex of the m. gastrocnemius (Achilles reflex). Selection of this test was based on its simplicity and quantity of information. The tendon reflexes in man are well known. Numerous studies indicate their monosympathetic nature, their close connection to the system of muscular reception, and establishes their similarity to the classical /166 tension reflex, whose functional organization was analyzed in detail (Figure 1).

For constructing the curve of implication which reflects the relationship of amplitude of the reflex to the strength of the stimulus, strokes on the tendon calibrated according to the force were used. A small hammer with a built-in sensor for recording the intensity of the effect were used for the strokes. Electromiographic responses of the m. gastrocnemius and the m. tibialis anterior were recorded by surface electrodes. The standard state of experimental conditions was achieved by standardization of the position of the test subject (lying on his stomach) and the position of the stimulating effect and contact electrodes. In the curve of implication, thresholds of the reflector responses were analyzed with maximum amplitude and steepness of its increase. The indicated parameters are not interconnected but reflect the different properties of the motoneuron population: excitation of both threshold elements of the pool (threshold), excitation of high threshold motoneurons (maximum amplitude) and the uniformity of the population (gradient of increase of amplitude). Comparing the characteristics of the curve at rest and when completing the motion with the other leg maintaining the position of the dorsal and plantar flexions, it was possible for us to evaluate also the state of intersecting synergies--one of the main spinal mechanisms playing an important role in organization of locomotor acts.

The state of control of motions was judged according to the data of stabilography, results of studying postion synergies and indices of cyclography of walking and jumping. Stabilography was conducted by a standard method using a stabilographic platform, a tension intensifier and an ink recorder. Recording of the stabilograms was carried out during 3 (preflight 6) minutes of which the first minute (2 preflight) the test subject stands in a comfortable stance with open eyes, in the second--with closed and in the third in the Romberg position) with arms extended in front and eyes closed. An example of analysis in the stabilogram was the frequency of oscillation of the overall center of gravity of the body (OCGB), calculated in percentage points of the total quantity of oscillations in the test. Besides /168 this, the stability of the test subjects was determined according to the indices of the test with the application of stimuli causing the body to lose equilibrium. External perturbations created measured jolts on the chest; they were provided randomly to the test subjects

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Diagram of the T-reflex arc

T-reflexes

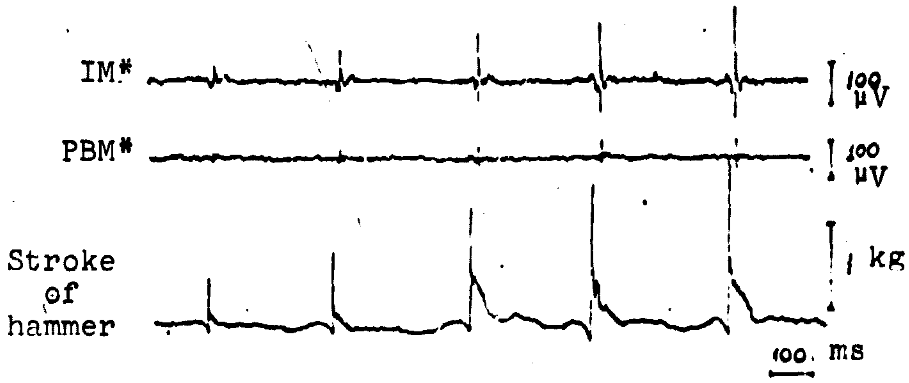

Figure 1. Diagram of the arc and examples of a recording of the tendon reflex. Symbols are on the Figure.

*[Translator's note: These abbreviations are not referred to in text].

while the test subject sharply (or slowly) raised a leg in response to /168
to a signal, keeping pressure on the plane of the support. Stability was evaluated according to the time of recovery of the equilibrium position.

It is well known that a disturbance in equilibrium which inevitibly must result from any perturbation (external or random) pushing the body out of an equilibrium position, prevents a correction activity of the muscle apparatus. Complex motor reactions organized precisely in time and space and which provide stability of the body, are called posture synergies. Studying the EMG of the muscle of the crus, the m. tibialis anterior and m. gastrocnemius, when standing and when carrying out the tests with perturbations, it was possible for us to evaluate the state of the control systems of posture synergies. Then, besides qualitative data on distribution of muscular activity precise quantitative indices could be obtained which characterize perturbation of the system: the thresholds of reaction, its amplitudinal and time characteristics, correlated with measured stimuli, etc.

Results of Studies and Their Consideration

The studies made showed significant changes postflight in the state of all of the links tested in the motor system.

According to the data of neurological and anthropomorphic studies, in the cosmonauts there were certain dysfunctions of the muscular periphery: a decrease in muscle tone, a small decrease in circumference of the crus, in the flight engineer (FE)--pronounced atrophy of the long muscles of the spine. Data of the Miotest then was nonuniform and one detected a pronounced variation in the indices of the electromechnical effectiveness of the muscles from test to test, a tendency to increase electromyographic cost of muscle exertion, an increase in /169
the process of coactivation of the muscles. In the crew commander (CC) postflight, one noted a marked and proven increase in the cost of exertion for the m. gastrocnemius when carrying out a static test (Figure 2). This increase was stable and was maintained until the 42nd day. The index of the electromechanical effectiveness of this muscle changed also in the dynamic test; however here these changes were not so large or constant. Postflight when operating in a dynamic state the antagonists fitness increased significantly (coactivation): the value of the integrated myogram of the m. tibialis anterior exceeded the preflight by 4.5 times and more. The electromechanical cost of static work of the m. quadriceps femoris postflight not only did not increase but even decreased (Table 1).

In the FE, in whom according to the data of clinical examination the muscular changes were significantly less precise, the results of the Miotest were more varied. The marked increase in expenditure of static and dynamic work of the m. gastrocnemius was noted only on the 9th day. On this same day, an increase was observed in the electromyographic index of the m. quadriceps femoris. On other days (days 2, 25 and 42 for the m. gastrocnemius, on days 25 and 42 for the m. quadriceps femoris) the Miotest indices were even decreased. As in the CC, Index of effectiveness of EMG

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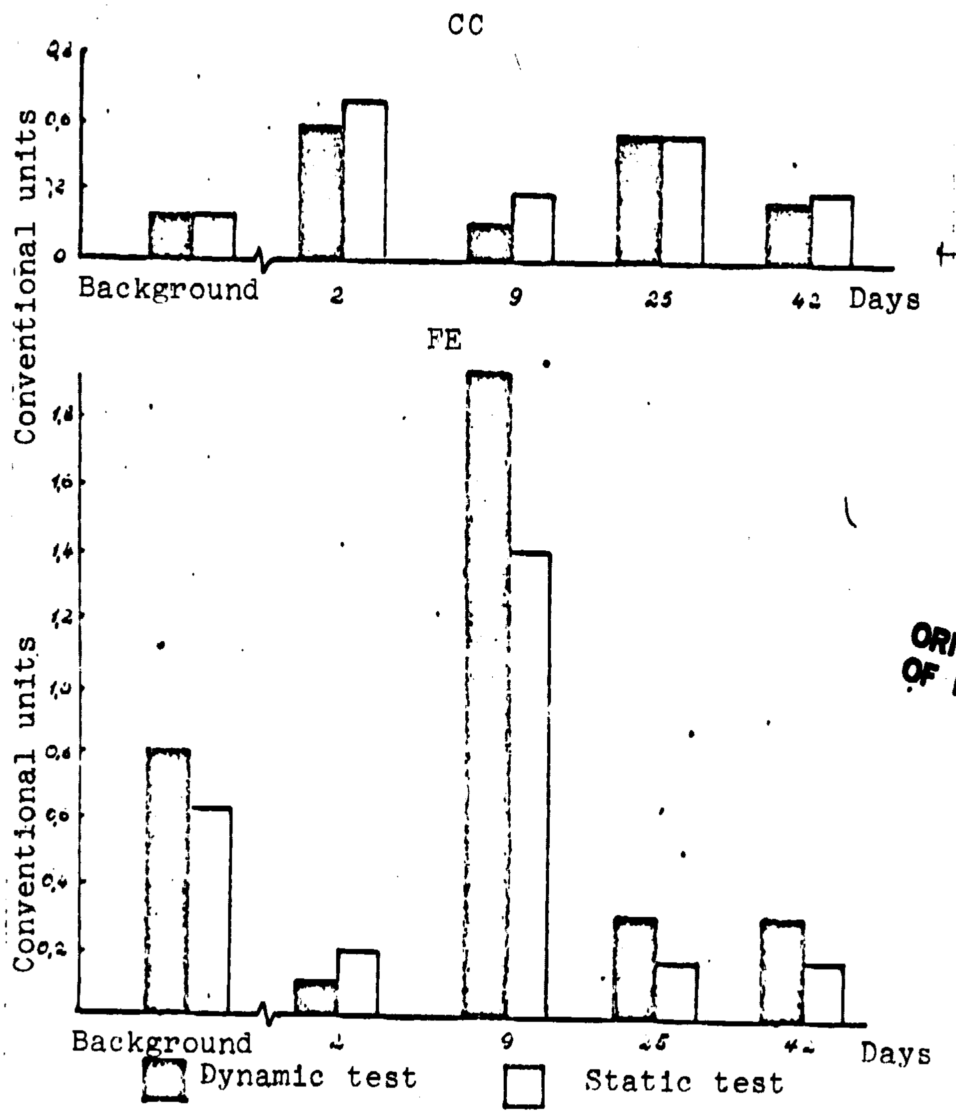

Figure 2. Index of electromechanical effectiveness of the muscle contraction.

Along the axis of the abscissa--days of the study. Along the ordinate axis--the index of electromechanical effectiveness (for dynamic conditions) and the total value of an integrated EMG (for static states).

TABLE 1. MIOTEST. DATA OF THE PREFLIGHT AND POSTFLIGHT EXAMINATIONS OF THE SALYUT-6 CREW MEMBERS

Days of the examination	Condition of operation	Static		Dynamic					
	Muscles studied	m. Gastrocnemius		m. Quadriceps		m. Gastrocnemius		m. Tibialis anterior	
	Parameters studied	EMEM conv. unit		IEMG conv. unit		EMEM conv, unit		EMEM conv. unit	
	Crew members	CC	FE	CC	FE	CC	FE	CC	FE
Preflight		0,I	6,2	46,7	22,5	0,15±0,0I	0,75±0,I5	0,29±0,04	[illegible]
2nd day		5,0	0,I	57,9	99,[illegible]	0,42±0,02	0,57±0,03	I,22±0,14	[illegible]
9th day		2,2	I5,0	10,0	105,0	[illegible]	I,90±0,09	7,47±0,45	[illegible]
25th day		2,5	0,I	11,8	21,8	0,[illegible]±0,02	0,32±0,02	I,58±0,I0	[illegible]
42nd day		I,5	0,4	7,I	6,2	0,22±0,0I	0,77±0,02	0,2[illegible]	[illegible]

[Commas in the tabulated material are equivalent to decimal points]

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postflight in the FE, a tendency toward coactivation of the muscle groups increased: the value of the integrated myogram of the m. tibialis anterior when carrying out plantar flexion increased on the 2nd and 25th postflight days by 4--5 times. /169

Thus, briefly summarizing the results of this section one can conclude that the Miotest does not show rough changes in the contractile properties of the muscles being tested. The peculiarities of the dynamics of the test indices in the FE could be due, apparently, to two circumstances:

-- the high level of electromechanical cost of exertion in the preflight studies which was the result of a high level of stress in this period; /172

-- nonstandard conditions for testing on the 9th day, immediately after a long absence from work.

An evaluation of the state of the proprioceptor inputs showed a sharp tendency toward hyperreactivity of the motor systems. In the CC on the second postflight day one noted a significant decrease in the thresholds of vibration sensitivity in all the support points of the foot in all ranges of frequencies tested. An increase in sensitivity was found and retained for all frequencies up to the 25th and for the 63rd, 125 Hz up to the 42nd day. At the same time, in the first postflight test, one observed a sharp decrease in the thresholds of muscular sensitivity: thresholds of the tendon reflex amounted to less than 200, 0g together 900, 0--1200, 0g preflight (Figure 3). In distinction from ordinary states of hyperreactivity, the decrease of thresholds of the reflex was accompanied by a marked decrease in maximum amplitude of the response, stably retained up to the 42nd day of the study (Figure 4). The interextremity reflector effects were significantly disturbed postflight: random extension of the m. gastrocnemius (dorsal flexion) of the other foot, preflight which caused a deep suppression of the reflex (Figure 3), now does not have a significant effect on its amplitude. Disturbance of thresholds and mechanisms of the interextremities synergies were temporary and levelled off completely by the 9th postflight day.

The data of studies on the FE in this section were similar to data on the CC. The only exception was the results of determining the thresholds of sensitivity of the support and muscle inputs which indicate not an increase but a decrease in sensitivity. As in the Miotest case, this change in the sign of the effect was, obviously, the result of relative inadequacy of the control values of the parameters studied obtained on days of rigorous prelaunch operations when the reactivity of the cosmonauts was increased (see the low /175 values of the T-reflex preflight).

Briefly summarizing the results of studies in this section, one can conclude that a lengthy flight caused a significant increase in reactivity of the main proprioceptor inputs (similar changes in thresholds of the otolithic reflex were obtained by a group of coworkers who studied the state of the vestibular apparatus; see the appropriate section on response). This increase in sensitivity was

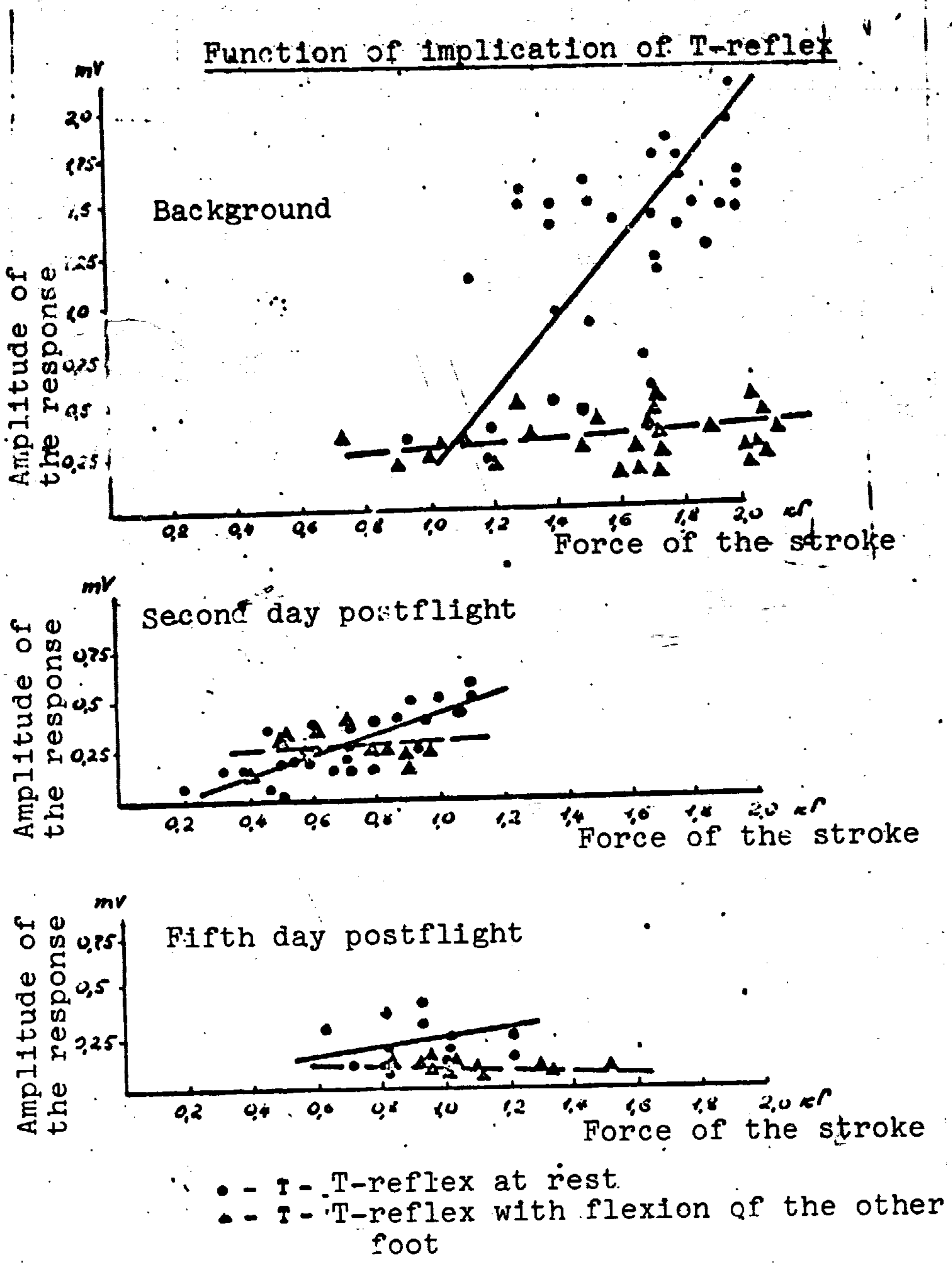

Figure 3. Diagram with dots showing the results of studying the tendon (Achilles) reflex in the CC.
Along the axis of the abscissa--intensity of the stimulus, kg.
Along the ordinate axis--amplitude of the reflector response, mV.
Dots--the value of the T reflex at rest: triangles--the same when flexing the other foot.

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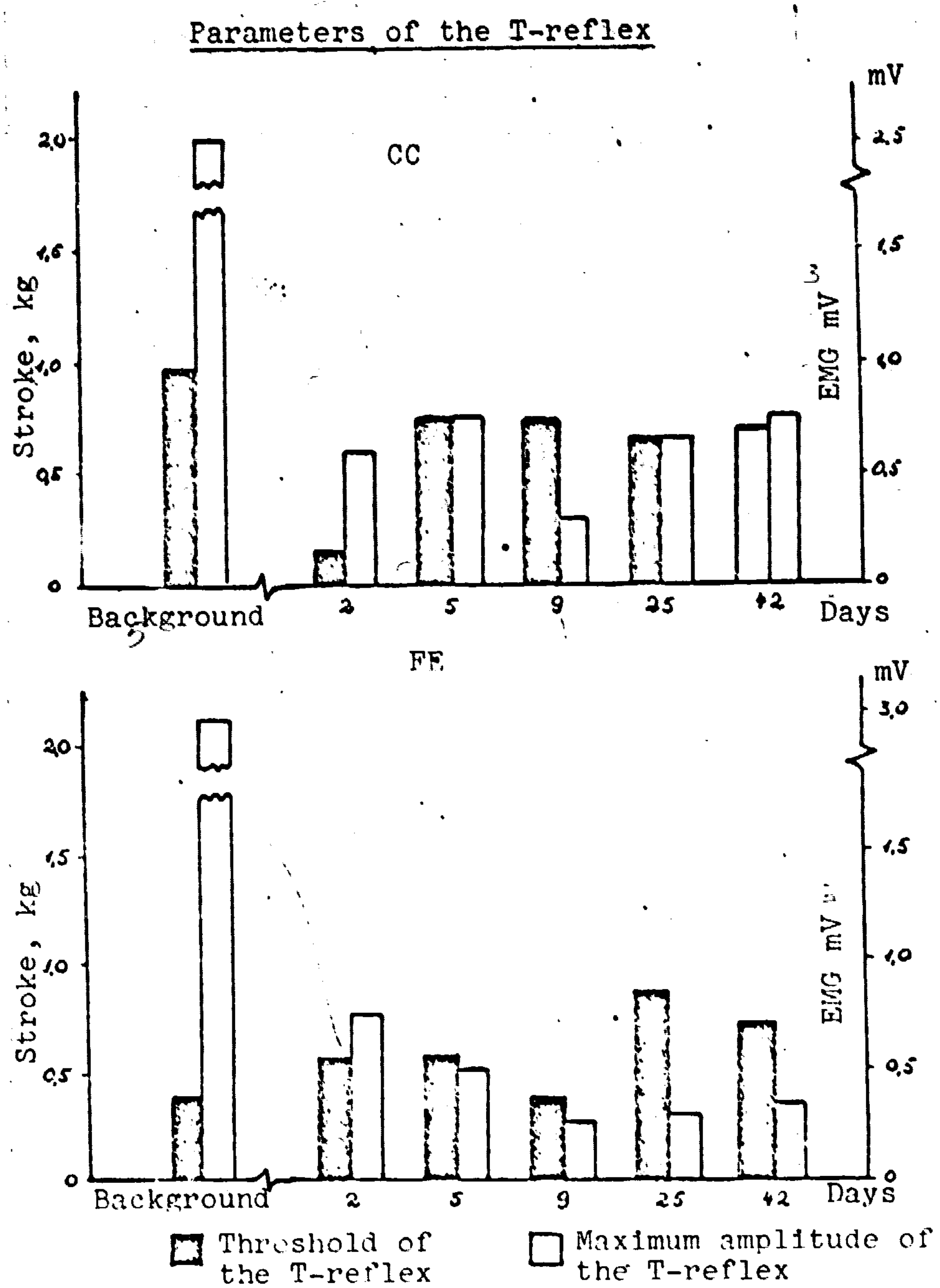

Figure 4. Threshold and maximum amplitude of the tendon reflex. Along the axis of the abscissa--days of the study; along the ordinate axis--intensity of the threshold stimulus, kg and stimulus, kg and maximum amplitude of the T-reflex, mV.

temporary and caused, apparently, not by the periphery, that is, changes in the properties of the receptors at the center which changed sensitivity to the signal being studied. Using this hypothesis the fact that a similar decrease in thresholds of muscle reflector reactions was noted in the test subjects after immersion hypokinesia in experiments with testing the H-reflex is important; here the stimulus was not the receptor but directly the motoneuron. The shifts in mechanisms of the interextremity reflector interactions postflight were as deep and short lived. One should not exclude the fact that the basic one of these was the changes considered above in reactivity of the spinal system. Moreover, the marked flattening of the curve of implication noted in both cosmonauts and the stable decrease in maximum amplitude of the reflex indicated a decrease in the number of motoneurons implicated in the reflector contractions. At the present time, we do not have data available to make it possible to correlate this phenomenon with any kind of concrete mechanism. However, inasmuch as the examinations did not show large muscle atrophy in the crew members, one can think that it had a functional character and reflected a decrease in sensitivity of the high threshold (phase type) motoneurons to muscular afferent input. /175

Particularly deep and long term disturbance were apparent postflight in the activity of the system of motor regulation. The first of these stabilographic studies showed marked changes in the structure of the stabilographic curve. While preflight the stabilograms of both crew mwmbers were characterized by polymorphous variations, including waves I, II, III magnitude, certain individual perculiarities of the frequency spectrum were apparent such as: predominance of oscillation with a period of 0.2--0.5 s in the CC curves and oscillations of the tremor type (7--8 per second) in the FE (Table 2) postflight the dominant oscillations became high frequency oscillations of the tremor type recorded both in the comfortable and the load positions (Figure 5). As is apparent in the drawing, preflight in the CC, the oscillations of this type were not recorded at all, in the FE curves they were apparent, however the amplitude of the waves was insignificant. In the EMG of the m. gastrocnemius and the m. tibialis anterior, these oscillations corresponded to a rhythmic group activity at a frequency of 3--9 per second. The amplitude of the electromyographic volleys was greater by two than the control, reaching 200 μV and more. Then, in the CC, the activity of the m. gastrocnemius was predominant and in the FE--the m. tibialis anterior, the activity of the m. gastrocnemius in this case was suppressed. The most pronounced changes in the posture stability were detected when conducting tests with stimuli. The time for recovery of equilibrium both with external and with random disturbances of the equilibrium position were proved to be increased to 1--2 s for external and to 3--5 and more seconds for random perturbations (Figure 6). Recovery of the OCGB position was accomplished with "reregulation," involving a large excess of correction forces. All of the shifts described were stable and were recorded up to the 42nd day of the study, although their expression gradually disappeared. The electromyographic analysis of correction responses to external and random perturbations indicated that a decrease in posture stablity in the cosmonauts was closely connected, and apparently, caused by deep /176

TABLE II. THE FREQUENCY SPECTRUM OF THE STABILOGRAMS OF THE SALYUT-6 CREW PREFLIGHT AND POSTFLIGHT

	Duration of the oscillation	0.2-0.5 s		1.0-2.0 s		2.0 and more s	
	Experimental conditions	Preflight %	Day 42 %	Preflight %	Day 42 %	Preflight %	Day 42
CC	Comfortable stance	55	63	37	17	8	-
	Eyes closed	72	not studied	24	not studied	4	not studied
	Romberg position	62	93	25.0	-	13	-
FE	Comfortable stance	89	not studied	-	not studied	11	not studied
	Eyes closed	82	80.4	18	19.6	-	-
	Romberg postion	100	92.2	-	7.8	-	-

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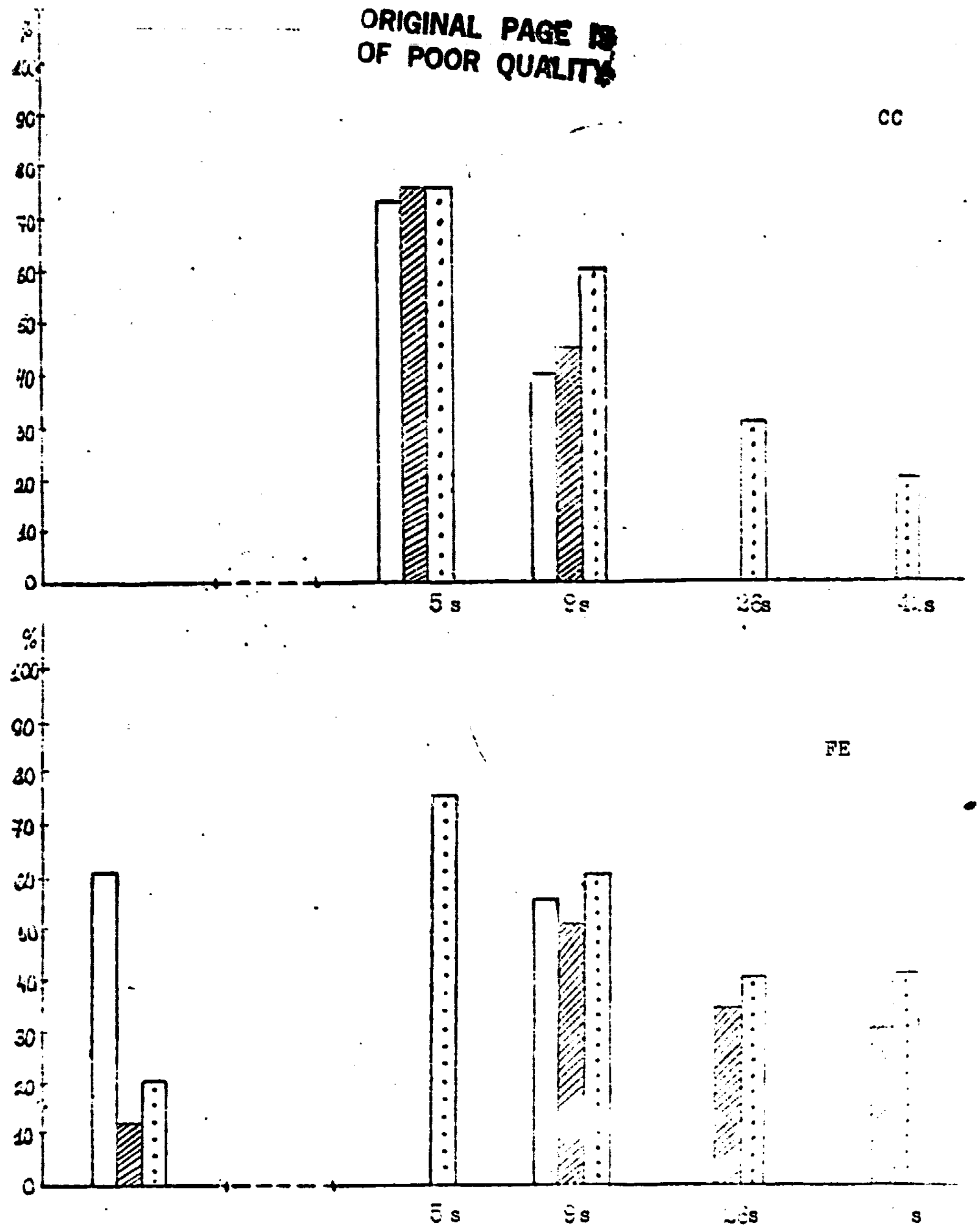

Comfortable stance

Standing with eyes closed

Romberg-position

Figure 5. Dynamics of the high frequency component in the structure of the stabilogram

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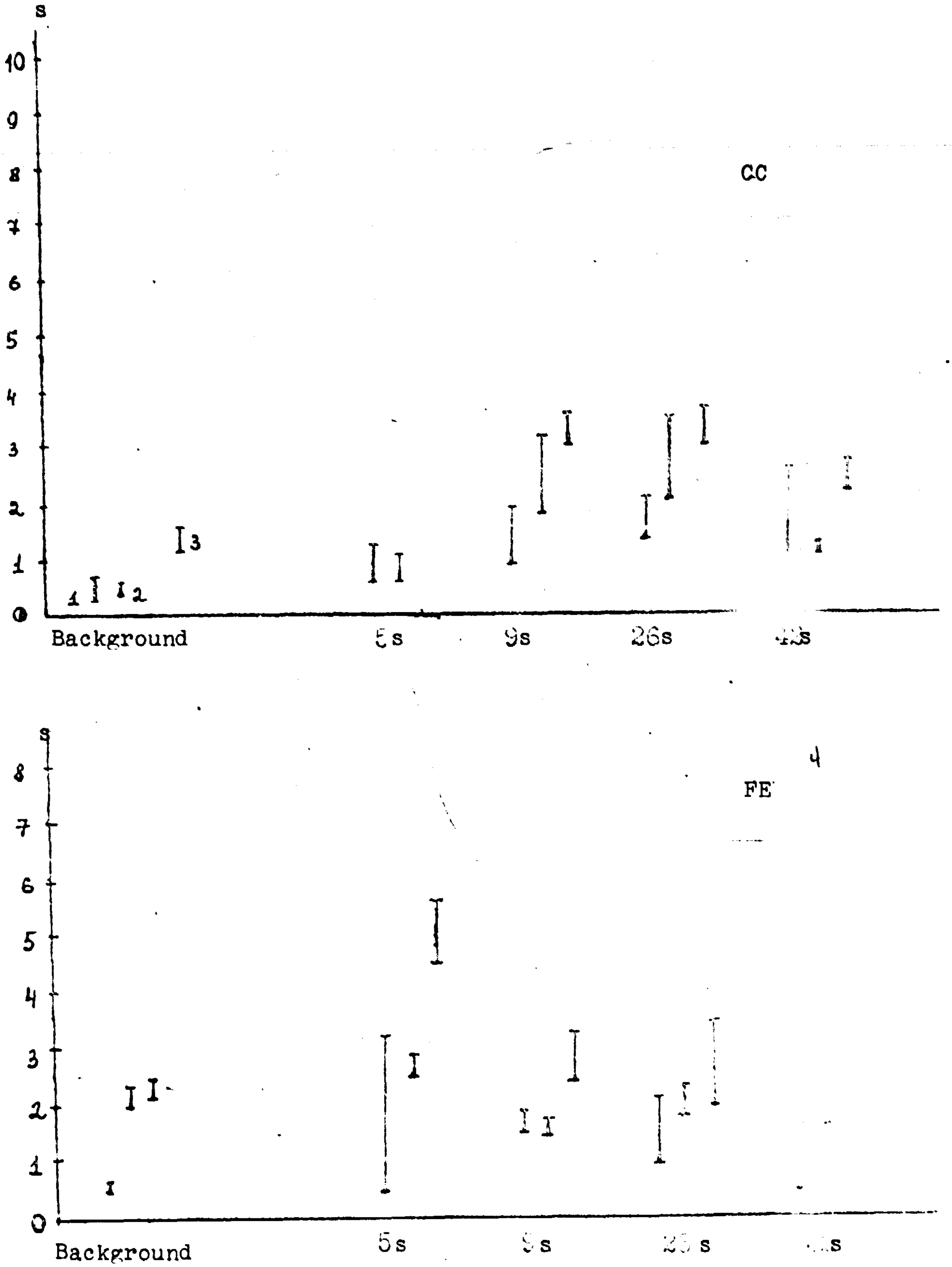

Figure 6. Time of compensation for perturbation of external (1) and random (2, 3)

disturbances in the position synergies. Preflight, the electromyographic response to measured jolts to the chest was characterized by a high amplitude stimulus of the flexor which occurred 60μs after the jolt and a slowing down of the EMG of the extensor, beginning somewhat earlier and lasting longer than the activity of the flexor (Figure 7). The amplitude and duration of the electromyographis response showed a direct relationship to the force of the stimulus, the thresholds of the responses in our studies amounted to 6 and more kg. /176 /180

Postflight, the thresholds of the correction responses were noticeably decreased, reaching three or less kg; their amplitude and duration sharply increased then the flexors and extensors operated synchronously (Figure 7). When completing random deviations, the position restructuring which provides stability of the body position were completed with a large delay (400--500 ms and more as opposed to 200 ms preflight), their drawings, amplitude and duration did not correspond to the parameter of local motion and altogether they did not provide reliable stability and rapidity of the recovery of the initial position. Similar changes in the position synergies were noted in the FE. However, in distinction from the CC, the amplitude of the electromyographic stimuli of the flexor in the FE was not increased but was significantly decreased; even deeper were his disturbances in position synergies when completing random deviations. The shifts noted in characteristic posture synergies were recorded, gradually attenuating, to the the 42nd day. The process of their recovery had all of the characteristics of retraining.

The studies carried out successfully demonstrated the independence of the shifts caused by a long-term stay in weightlessness in a state of different links in the motor system: the least deep and longest were changes in the muscle length, the largest in the system of regulation of whole coordinated acts. This result of work which we consider basic, in turn, shows self containment, and independence in the nature of the dysfunction recorded in different links and consequently, differences in the mechanism of their development.

3.4. Studies of the Vestibular Function and the Function of Perceiving Space /182

Method

When conducting the study the following were determined:

1. The intensity of the otolithic reflex according to the value of counterrotation of the eyeball using a visual sequential method when transferring from a vertical position to a horizontal (from the right to the left side)--a modification of the method of indirect otolithometry according to Fischer and Fluur [1, 2].

2. The function of the semicircular canals according to the value of the thresholds of sensitivity to angular acceleration (according to the nystagmus and sensory component) using an automatically

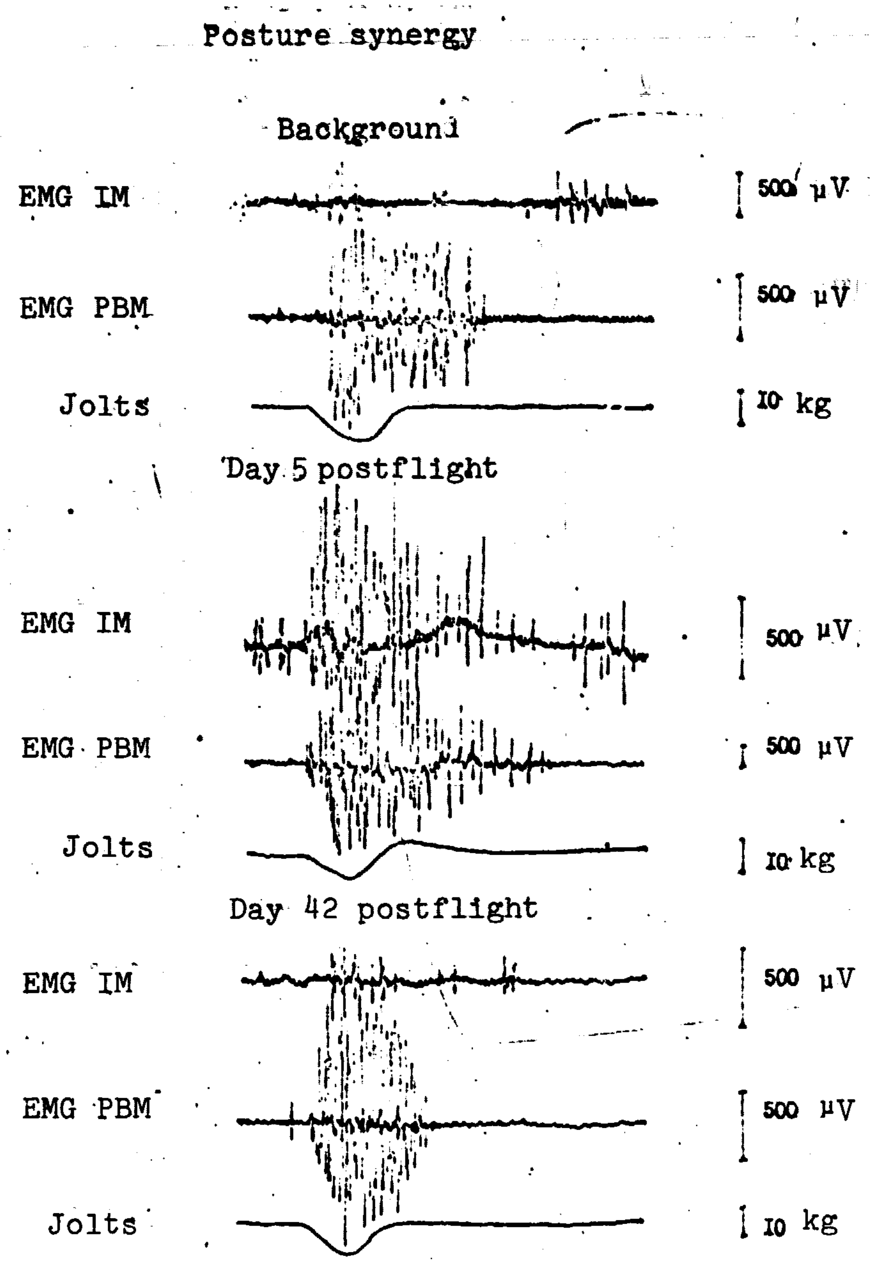

Figure 7. Examples of correction responses to the external perturbations recorded in the CC. Symbols are on the drawing.

rotating armchair. The perception of change in the value of angular velocity were determined at a constant value of effective angular velocity 1°/s². /182

3. The degree of expression of reciprocal ratios between the otolithic organ and the semicircular canals (according to the nystagmus and sensory component) using the "otolithic reaction" (OR) test of Voyachek (measured effects of angular acceleration with subsequent measured stimui of the otolithic apparatus).

4. The function of perception of spatial coordinates (gravitation verticals and horizontals) using the Vertical instrument [3] in the following positions: sitting, in horizontal position on the right and left sides.

5. The level of vestibular vegetative stability according to the expert program of clinical and physiological examinations, the transferrability of the complex of tests with the predominant effect on the vestibular system (cumulative effect of Coriolus acceleration according to the Bryanov method, cumulative effect of straight line accelerations on the fourth rolling rod of Khilov, measured effect of the optokinetic effects with transfer of the test subject to an unstable support, measured effect of angular acceleration--the Barani test).

The otolithic reflex, thresholds to angular acceleration and the function of perception of spatial coordinates were studied 3 and 5 times with a background examination (on days 30--45 preflight) and a similar number of times on days 1--2, 4--5, and 8--9, and they were studied 1 or 2 months postflight.

Determination of the level of the vestibular vegetative stability was conducted fully for days 60--45 preflight and for days 3--5 before the launch--according to the transferrability of the Barani test and the Voyachek OR test, and according to the completed expedition on days 4--5 and 8--9, and also according to the transferrability of the Barani and Voyachek OR tests.

Studies were conducted on crew memeber of two long-term expeditions on the Salyut-6 station: the length of the flight for the first expedition was 96 days and for the second, 140 days. /183

Results and their Consideration

Data of Background Examination

During background examinations, the indices of intensity of the otolithic reflex in all the cosmonauts was within limits of variation of the physiological norm ($N = 12° \pm 7°$) established using this instrument and corresponding to 5°--12°. The otolithic reflex in all, except the commander of the first expedition, was, as a rule symmetrical for the value of asummetry (Δ) did not exceed the boundary of the physiological spread (NΔ less than 4°) and amounted to 2°--3°.

In the commander of the first expedition, the otolithic reflex in the background was asymmetrical and its value exceeded the physiological spread (on the right side --2°, on the left --10°).

The initial values of the thresholds of sensitivity to angular acceleration in all of the cosmonauts, except the commander of the first expedition, were within limits of physiological variations of this index obtained with mass examination on a given test stand for vestibular stability of healthy persons (N = 2°--6°) and corresponded to 4°--6°. The values of the acceleration thresholds were practically symmetrical (Δ did not exceed 2°). In the commander of the first expedition, the thresholds for angular acceleration were increased to 11° and were asymmetrical (Δ = 6°).

The indices of precision of perceiving spatial coordinates with background studies in all, except the flight engineer of the first expedition, lay within limits of variation of the physiological norm (for the vertical position 0--1°, for the lateral horizonatal--18° ± 5°). The difference in errors in perceiving spatial coordinates in the lateral positions either were absent or were within limits of physiological asymmetry--less than 5° (Δ less than 5°). In the flight engineer of the first expedition of the Salyut-6 station errors in perceiving spatial coordinates in lateral positions exceeded the spread of the physiological norm (in the position on the left side--32°, on the right--28°).

Studies in the background period of the reciprocal ratios between the otolithic organ and the semicircular canals showed in all, except the flight engineer of the first expedition, a normal interaction between them (a decrease in vestibular somatic and vestibular sensory reactions was within limits of 1/3). In the flight engineer, with a tilt of the head after rotation, slowing of the reactions was absent in the semicircular canals.

During analysis of materials of the study, data of the expert de- /184
termination of vestibular stability obtained during the primary selection were taken into consideration, that is, the preflight period of examinations for all cosmonauts had uniformly high indices of vestibular vegetative stability as the result of systematic vestibular training conducted according to an individual plan in the training process. In three cosmonauts out of 4, with primary vestibularometric examinations, the average level was determined of vestibular stability that is, vegetative reactions of average and mean expression at the end of the research were recorded in them.

Subjective Characteristics of the Effect of Flight Factors on the Systems Studied

All of the cosmonauts of both expeditions in the first 24 hours of flight showed an illusory reaction of an inversion type: in the flight engineer of the second expedition this reaction occurred after 2 hours in weightlessness; in the others--immediately upon entering weightlessness. Two of the flight illusions were successfully fixed to some kind of object, fixed to the armchair or elements of autotraining. At first the illusion occurring lasted for several minutes or up to 4 hours, later on in flight they again occurred episodically, most often at a moment of intensifying motor activity or under the effect of optokinetic stimuli. The perception of "blood congestion" in the head was noted in all cosmonauts 1.5--2 hours after transfer to weightlessness and this reaction lasted more or less markedly for a period of 5--7 days. During the first 3 days both the commander and the flight engineer in the first expedition noted vestibular discomfort when moving the head in the form of dizziness, slight nausea, and a more marked vestibular vegetative discomfort in the commander of the first expedition. A stronger but shorter (3 day) period of adaptation occurred in the crew commander of the first expedition, less marked but more persistent in the flight engineer of the first expedition, less marked and shorter--in the flight engineer of the second expedition. For 10 days before completion of the flight, the commander of the second expedition again had a slight vestibular discomfort when increasing motor activity (turning the head and torso).

After landing, all of the cosmonauts for the first few days noted statokinetic disorders in the form of instability in the Romberg position and sweating when walking; in both commanders, besides the statokinetic disorders, one observed marked vestibular vegetative disorders: dizziness, nausea, tendency to vomit, particularly increased with movement of the head in a vertical position. /185

Data of Postflight Examination

Postflight examination of the crews of the longterm space expeditions made it possible to discover the following peculiarities of the functions studied.

Combined data of the indices of the functions studied are presented in Tables 1 and 2, and the dynamics of separate indices in Figures 1--3.

In the first and second days postflight (Figure 1) stimulus of the otolithic apparatus occurred with testifies to the two-sided (in the crew of the second expedition) or one-sided (in the crew of the first expedition) hyperreflexia of the otolithic reflex. A more pronounced increase in the otolithic reflex was noted in members of the second expedition (3--5 times in comparison with the background).

After flight in all of the cosmonauts, but more pronounced in the commander of the second expedition, one observed the phenomenon of asymmetry which in both flight engineers and the commander of the first expedition developed due to an increase in the reflex in the position on the right side (D > S by 4°--8°) and in the commander of the second expedition--due to hyperreflexia in the position on the left side (S > D by 12°). In this period, all of the cosmonauts expressed complaints of statokinetic disorders which, in subsequent days were confirmed by objective stabilographic studies.

TABLE 1. INDICES OF THE VESTIBULAR FUNCTION AND THE FUNCTION OF PERCEIVING SPACE IN THE CREW OF THE SALYUT-6 STATION EXPEDITION

	Index	Accuracy in percieving simple coordinates (°)			Otolithic reflex (°)		Thresholds of angular acceleration (°/s)		Evaluation of interaction of the otolithic organ and simicircular canals			
									Rotation		Rotation and tilting	
	Days	Sitting	Right side	Left side	Right side	Left side	Right side	Left side	PNg (s)	Illus. (s)	PNg (s)	Illus. (s)
Commander		1.0	20	20	2	10	5	11	31	20	25	18
	Postflight (days)											
	2	0.5	20	23	12	8	5	6	13	8	12	10
	8	2.0	18	22	9	14	6	12	21	19	21	18
	32	0.0	20	16	7	6	7	13	14	36	23	17
Flight Engineer		1.0	28	32	12	12	3	6	21	13	28	15
	Postflight (days)											
	2	0.5	37	26	14	8	-	-	-	-	-	-
	5	1.5	20	25	8	10	6	12	25	22	19	10
	32	0.0	20	12	12	3	6	8	14	12	20	16

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TABLE 2. INDICES OF THE VESTIBULAR FUNCTION AND THE FUNCTION OF PERCEIVING SPACE IN MEMBERS OF THE SECOND EXPEDITION OF THE SALYUT-6 STATION EXPEDITION

	Index / Days	Accuracy of perceiving spatial coordinates (°)			Otolithic reflex (°)		Thresholds of angular acceleration (°/s)		Evaluation of the interaction of the otolithic organ and semicircular canals			
									Rotation		Rotation + tilting	
		Sitting	Right side	Left side	Right side	Left side	Right rotation	Left rotation	PNZ (s)	Illus. (s)	PNZ (s)	Illus. (s)
Commander	Background	I	20	20	7	5	4	4	30	8	I7	6
	Postflight											
	I	3	2	I5	I4	26	-	-	-	-	-	-
	5	3	6	5	5	I0	5	7	2I	I3	20	I3
	9	0.5	8	I2	8	I0	4	3	28	I4	23	7
	60	0.5	I7	I7	6	5	-	-	-	-	-	-
Flight Engineer		0	I6	22	8	5	5	7	28	2I	26	I4
	Background	I	I3	27	25	2I	-	-	-	-	-	-
	I											
	5	0.5	I8	20	22	20	I5	I2	I9	I6	3I	I9
	9	0	28	28	I5	I2	[illegible]	6	22	I6	20	I5
	60	0	I8	20	7	6	-	-	-	-	-	-

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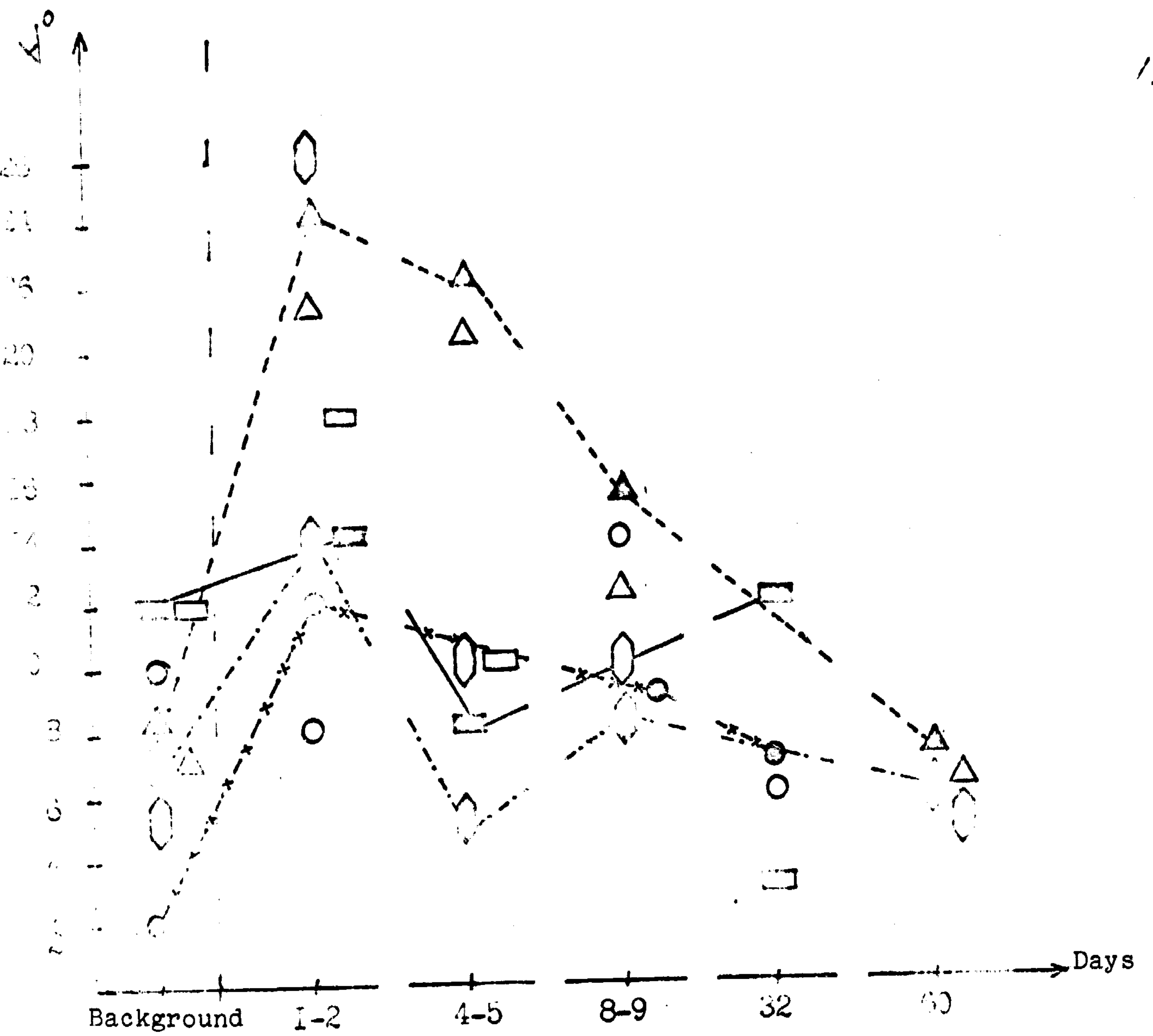

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Figure 1. Dynamics of the otolithic reflex postflight

Right side	Left side	
^	⬡	CC-II
△	△	FE-II
○	○	CC-I
▭	▭	FE-I

When examining the cosmonauts on the 5th days, in all of them except for the flight engineer of the second expedition, one noted a tendency toward normalization of the reactions and a decrease in asymmetry. Practical normalization of the indices of the otolithic function in the commander of the second expedition occurred on the 9th day postflight, in the commander of the first expedition, after a month and in the flight engineer of the first expedition on day 32 postflight again asymmetry was apparent in the indices of the otolithic reflex, whose direction coincided with that observed in the first days postflight. Unfortunately, no further study of the otolithic function in this cosmonaut was made.

In the flight engineer of the second expedition, a recovery of the indices of the otolithic function occurred more slowly with a study on the 5th and 9th days postflight there was no tendency toward normalization of the reaction and only during studies after two months did the otolithic reflex correspond to the background data.

A study of sensitivity toward angular acceleration was apparent /189 (Figure 2) in the crew of the second expedition in short term changes in the functional state of the cupulary apparatus which is characterized by an increase, particularly in the flight engineer (from 5° to 15°) in the thresholds, that is, a decrease in sensitivity and the appearance of asymmetry (Δ less than 5°).

In the crew of the first expedition, the increase in thresholds of acceleration perceptions in the first days postflight were practically absent. However, during studies on the 5th and 8th days, a manifestation of significant asymmetry was noted (Δ6°) in the threshold of sensitivity to angular acceleration which was retained in the commander a month postflight.

As to the interrelation between the otolithic organ and the semicircular canals postflight, reciprocity was observed in all the cosmonauts except for the flight engineer of the second expedition. A slowing reaction was absent in him with the otoliths on the nystagmus and illusory reaction with the semicircular canals during a shift in position of otoliths relative to the vector of gravitation.

When studying the function of perception of spatial coördinates in all the cosmonauts shifts were noted in the sensory sphere (Figure 3), characterized by the development in three cosmonauts of a significant asymmetry in error in perception of the gravitational vertical from lateral positions (Δ from 11° to 13°) and by a change in character of the direction in members of the crew of the first expedition in comparison with the physiological asymmetry observed preflight. In the commander of the second expedition, in a sitting position, an increase in error was noted up to 3° (in the background 0.5°--1°).

Vestibular vegetative stability which preflight in all of them was high, postflight in the flight engineer of the second expedition was decreased, that is, when conducting test rotational vestibulometric tests (the Barani and Voyachek OR tests) a vestibular vegetative reaction was noted in him of the first degree (dryness in the mouth,

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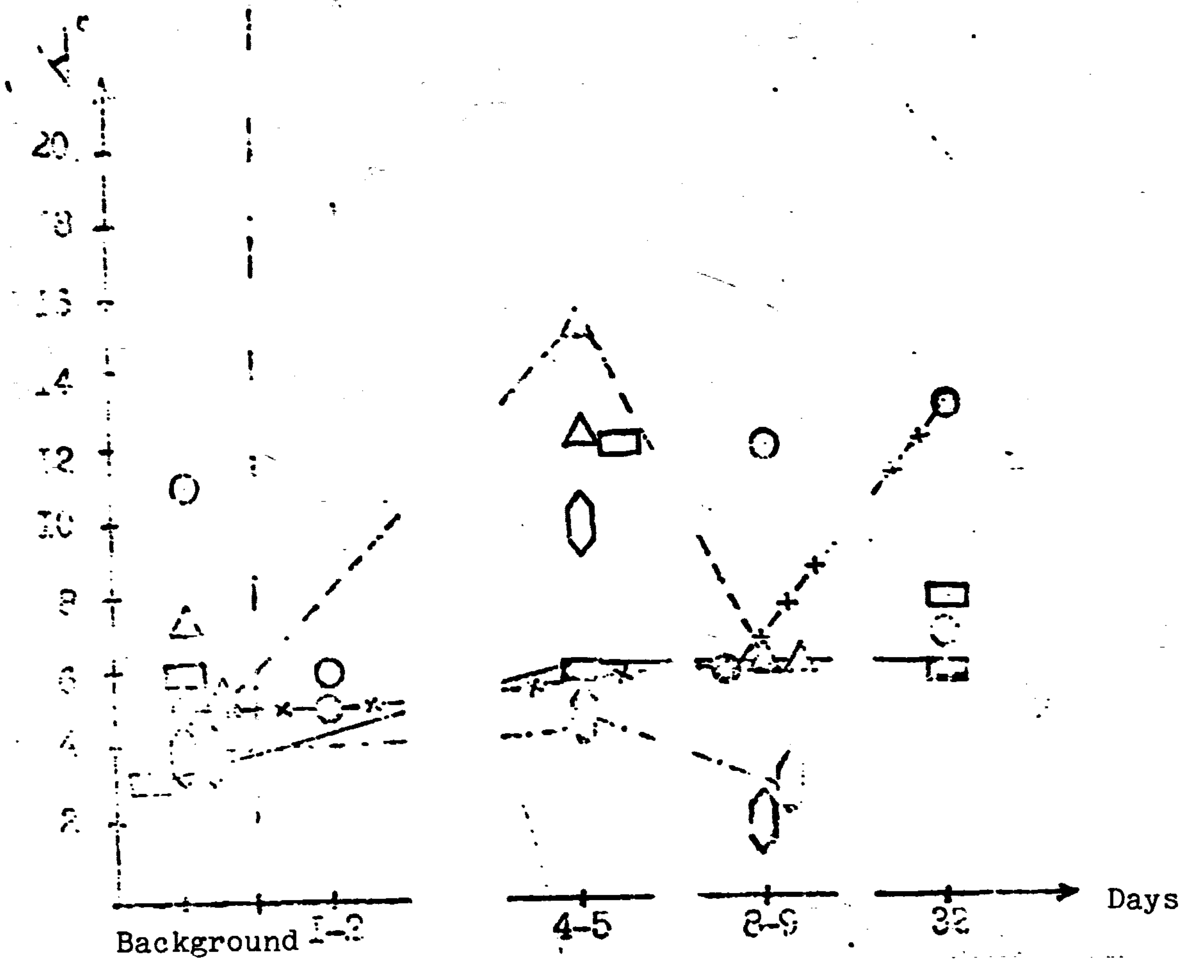
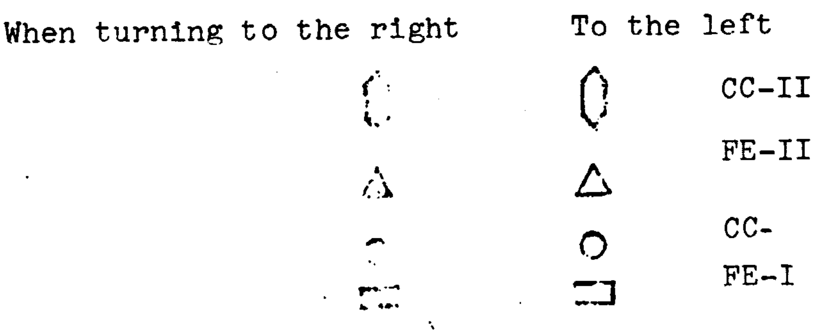


Figure 2. Dynamics of threshold sensitivity of the semicircular canals toward angular acceleration



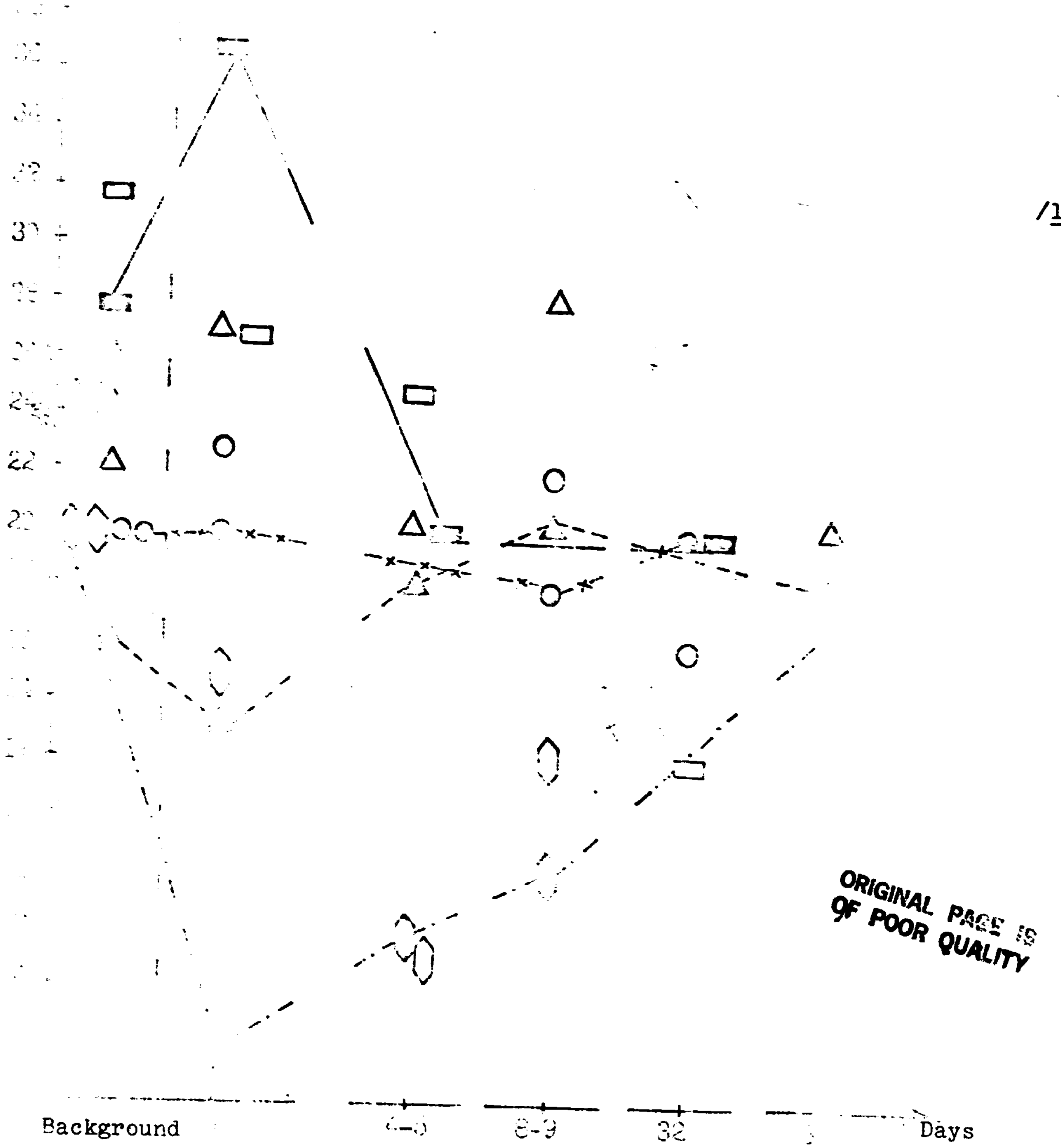


Figure 3. Dynamics of the indices of precision in perceiving spatial coordinates postflight in lateral positions

Right side   Left side

CC-II

FE-II

CC-I
FE-I

frequent deglutitory motions, paleness of the skin, increased cardiac rhythm on the FKG). /189

Thus, the results of the studies made give evidence of the change of sensory systems and, in particular, the vestibular analyzer under the effect of space flight factors.

In spite of the small quantity of observations one can talk to a certain degree about changes of unitypical directionality and about individual reactions.

Reactions noted either in all or in the 3rd and 4th examinations can relate to a shift in a common direction: /192

a) signs of excitation of the otolithic organ;

b) a decrease in sensitivity of the cupulary apparatus;

c) asymmetry of most of the indices studied (otolithic reflex, threshold of sensitivity of the canals, precision in perceiving spatial coordinates);

d) development of illusory reactions in flight.

The following are individual reactions:

-- the degree of expression of changes;

-- dynamics and time periods for the readaptation period;

-- the development of a vestibular vegetative symptomocomplex in the period of initial adaptation to weightlessness;

-- signs of a decrease in the vestibular vegetative stability postflight;

-- change in reciprocal ratios between with otolith organ and the semicircular canals.

The studies made, data of preceding flights [4, 5] and model experiments [6] do not make it possible to definitely show mechanisms which record shifts.

Apparently, a complex of factors is important: a breakdown in the functional systemization in the work of the analyzers, hematic spinal fluid dynamic shifts, and also change in the regulatory effects in conditions of space flight.

The data which we obtained give evidence, on the one hand, of the necessity for further development of prophylactic measures both on Earth and on board the station, and on the other hand, deepening of our studies including conducting flight experiments with the participation of cosmonauts and animals for a detailed understanding of the mechanism of the changes which have occurred.

The studies made do not make it possible to show the dependence of the reaction of systems studied on the initial level of vestibular vegetative stability which could be caused by the small number of observations.

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PART 4

BIOCHEMICAL, HEMATOLOGIC, IMMUNOLOGIC AND MICROBIOLOGIC STUDIES

The studies made during and after cosmic flight of varying /195 duration showed a number of principle biochemical, immunologic, hematologic and other changes of the internal media of the organism and also automicroflora of the integuments and mucous membranes. As a whole, the changes observed can be considered as the result of restructuring of the basic functions of the organism as a result of adaptation to a long stay in weightlessness, and also to subsequent adaptation to conditions of Earth's force of gravity. The study of morphology and the function of erythrocytes was particularly important in space flights lasting 96 and 140 days. This was due to the circumstance that preceding studies had shown in-flight and postflight shifts in the form of a decrease in the erythrocyte mass, total mass of hemoglobin, the content of reticulocytes, changes in the number and shape of erythrocytes. Moreover, it is well known that the average duration of life for erythrocytes amounts to 120 days. Therefore it was important to study their function after a 140-day stay in weightlessness. It is natural that long space flights also can not indicate a state of immunologic reactivity which made the conduct of immunologic studies necessary. These studies were directed not only at immunoreactivity and autoimmune changes but also to discovering hypersensitivity to a number of allergens of bacterial and chemical origin.

Studies of the state of automicroflora of the integuments of the intestine were particularly done, mainly, according to the results of postflight examination.

Later on, results are presented of biochemical studies, research on water-salt exchange and the function of kidneys, hematologic, immunologic and biochemical studies made during and after flight of the main expedition of the orbital Salyut-6 and Soyuz complex.

4.1. Results of Biochemical Studies /196

Biochemical studies made according to the program of the first main expedition on the orbital Salyut-6 station (OS) clearly showed that in cosmonauts who spent 96 days under the effect of spaceflight factors, definite changes occur in the biochemical indices, mainly similar to those which were noted earlier with shorter flights [1]. These changes are characterized by restructuring of the metabolic processes directed at maintaining homeostatis of the organism during long stays in weightlessness and during the period of readaptation to conditions of Earth's gravitation.

The purpose of the biochemical studies completed according to the program of the second main crew on the Salyut-6 OS was the study of character and direction of exchange processes and the state of the main regulatory systems of the organism of the cosmonauts, done in the 140-day spaceflight.

In this section, the following abbreviations are used: K.V.V.--cosmonaut V.V. Kovalënok; I.A.S.--cosmonaut A.S. Ivanchenkov.

Materials and Methods

The material for conducting biochemical studies was venous blood (serum and plasma) and the daily urine. Conclusions on the state of the main processes of the metabolism of the cosmonauts are based on a comparison of the results of biochemical analysis of the blood and urine made during the preflight (background) and postflight examinations. The background values were indices obtained for blood on day 27, and for urine on days 26, 25, 24, 5, 4, and 3 before the expedition. The postflight examination was made according to the following system: blood was taken on the 1st and 25th days after land- /197
ing, urine was collected on the day the flight was completed (day 0) in the 6 succeeding days and on day 10 after completion of the spaceflight.

In the blood serum, by colorimetric and spectrophotometric enzymatic methods, using a test set from the Boehringer, Mannheim GmbH firm, the content of the following was determined: glucose [2], total lipids [3], triglycerides [4], non-esterified fatty acids--NEFA [5], and the activity of lactate dehydrogenase enzymes--LDH [6], malate dehydrogenases--MDH [7], isocitrate dehydrogenase--ICDH [8], α-oxybutyrate dehydrogenase--α-OBDH [6], creatin phosphokinase--CPK [9], alanine aminotransferase--ALT [10], aspartate aminotransferase--AST [11], alkali phosphatases--AlP [12]. The isoenzyme spectrum of MDH and LDH were determined by a method of electrophoresis in a polyacrylamide gel [13]. The content of lactate [14] and pyruvate [15] were determined in whole blood.

Concentration of hormone and biologically active substances: insulin, thyreotropic hormone (TTH), somatotropic hormone (STH), cortisol (F), renin, aldosterone, testosterone, thyroxin (T_4), triiodothyronine (T_3), the values of effective thyroxin (CET), cyclic AMP and GMP (cAMP and cGMP), prostaglandins (PG)--A + E, $F_1 - \alpha$ and $F_2 - \alpha$ and the content of aldosterone in the urine; these were all determined by a method of radioimmune analysis using standard sets (KIT) from the Cea-Ire-Sorin, Byk-Mallincrodt, Amersham, Clinical Assays. For determining the content of total 17-oxycorticosteroids (17-OCC) in the urine and their free form and paired compounds with glycuronic and sulfuric acids, the Silber, Porter method was used [16], and for 17-ketosteroids (17-KS)--by the M.A. Krekhova method [17].

An evaluation of the activity of the sympato-adrenal system (SAS) was made for determining the content of epinephrine (E) and /198
norepinephrine (NE) in the blood [18], dofamine (D') in the blood [19] and according to excretion with the urine of free forms of E, NA, DA, DOPA [18], bonded form E, NE and DA [20], free and bonded forms of metanephrine (MN), normetanephrine (NMN) [21], and also vanillyl-mandelic (VAA) and homovanillic (HVA) acids [22]. Moreover, a qualitative evaluation was made of changes of SAS

activity using calculation of indices of the relative activity of change of catecholamines (CA) and their metabolites [23].

Results and their Discussion

The results of the studies made are presented in Tables 1--4.

Examination in the preflight period showed that the biochemical indices studied in the blood and urine basically are within limits of the generally adopted norm. Existing deviations from the norm of certain indices in this period will be indicated according to analysis both of the preflight and postflight data.

The results of the study of content of hormones and biologically active substances in the blood are presented in Table 1.

The content of cortisol in the blood on the first day after completion of the flight increased in both cosmonauts by 60%; on the 25th day, the level of cortisol in I.A.S. returned to the preflight value whereas in K.V.V., the content of cortisol in this period continued to exceed the preflight value by 50%.

The level of aldosterone in the blood of K.V.V. somewhat exceeded the norm of the preflight, sharply (by 3.5 times) decreased on the first day after landing whereas in I.A.S. it was practically unchanged. On the 25th day of the postflight period, the content of this hormone in the blood in both cosmonauts noticeably increased relative to the first day, and was close to the preflight value in K. V. V. exceeding it by 1.5 times in I.A.S. The activity of renin in the blood plasma, exceeding the generally adopted norm in both cosmonauts in the preflight period, on the first day after landing decreased in them to normal values. On the 25th day of the readaptation period, the level of activity of renin in I.A.S. significantly decreased in comparison with the preflight level and the first days of the postflight period, being less than the preflight value by more than 3 times whereas in K.V.V., the activity of renin noticeably increased to values exceeding the norm and were found at the preflight level. /200

The study of hormones in the pituitary-thyroid gland system showed that in I.A.S, on the first day after landing, the concentration of TTH and T_4 increased with a certain simultanous decrease in the value of CET. One should note that in this cosmonaut, the CET before flight was higher than the normal. On the 25th day of the readaptation period, a tendency was noted towards a return of the level of TTH, T_4 and CET to the preflight value. In K.V.V. one noted similar but opposite directional dynamics in changes of these indices. The content of T_3 in the blood in both cosmonauts increased in the first day after completion of flight; in K.V.V. this index remained decreased up to the 25th day of readaptation whereas in I.A.S. it somewhat exceeded the preflight values.

The entire period of readaptation (1st and 25th days) was

TABLE 1

Indices	K.V.V.			I.A.S.			Boundaries of the standard
	Preflight day	Postflight day		Preflight day	Postflight day		
	− 27	+ I	+ 25	− 27	+ I	+ 25	
Cortisol mg%	9,0	I4,0	I3,6	8,6	I3,8	9,4	7 − 25
Somatotropic hormone (STH) ng/ml	3,I	3,6	2,5	I,0	2,6	2,0	0 − 6,5
Renin hg/ml/hr	3,03	2,38	3,43	2,84	2,I8	0,77	0,2 − 2,7
Aldosterone pg/ml	I26,0	36,4	96,0	36,0	44,7	54,0	I2 − I25
Thyreotropic hormone (TTH) ng/ml	I,4	0,8	0,7	0,8	I,4	I,I	0,34−I,5I
Thyroxin (T_4), mkg%	8,8	6,62	7,6	9,I	I0,8	7,82	5 − I3,7
Triiodothyronine (T_3) ng%	I84,5	I05,4	I30,2	I42,6	I30,2	I55,0	80 − I80
Coefficient of effective thyroxin	I,09	I,I0	I,06	I,20	I,04	I,08	0,86−I,I3
Insulin μunit/mℓ	I6,2	28,0	20,0	I8,4	20,0	I6,2	3 − 22
Testosterone ng%	500	3I0	400	530	620	460	220 − 980
cAMP pmol/ml	2	II	I5	5	II	I5	I0 − 30
cGMP pmol/ml	I,0	2,5	5,0	I,0	2,5	5,5	I,8 − 6,0
Prostaglandin (PG) A+E ng/ml	6,67	0,60	0,I67	6,67	0,I83	0,073	2,8 − 3,2
Prostaglandin (PG) F_1 - α ng/ml	0,7	0,296	I,05	I,4	0,5	0,9	0,6 − I,0
Prostaglandin (PG) F_2 - α ng/ml	0,6	0,25	0,23	0,58	0,27	0,25	0,6 − I,0
Epinephrine μg/l	0,6	I,67	I,I2	0,6	I,52	0,97	0 − 0,7
Norepinephrine μg/l	0,82	I,97	I,08	0,35	I,65	I,I7	0 − I,3
Dofamine μg%	−	2,46	0,83	−	2,I4	0,9I	0,6 − 0,72
Epinephrine/norepinephrine (E/NE)	0,73	0,85/II6,	I,04/I42,5	I,7I	0,92/53,8	0,83/48,5	
Norepinephrine/dofamine (NE/DA)	−	0,80	I,30/I62,5	−	0,77	I,29/I67,5	

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TABLE 2

K.V.V.

Indices	Preflight, days						Postflight, days							
	- 26	- 25	- 24	- 5	- 4	- 3	0	+ I	+ 2+	+ 3	+ 4	+ 5	+ 6	+ 10
17-oxycorticosteroids total mg/24-hr 1,31--7,39	6,95	8,62	4,52	8,05	7,I7	5,70	I0,65	9,50	2,45	6,3I	I0,71	7,87	4,05	3,4[illegible]
Free 1--14%	24	20	2I	II	I3	24	5	6	I2	I6	I6	2I	20	22
Glucuronides 60--80%	49	55	45	7I	74	55	90		60	4I	80	76	67	40
Sulfates 14--24%	27	25	34	I8	I3	22	5	6	28	43	4	3	I3	39
17-ketosteroids 7-26 mg/24-hr	5,6	6,6	2,9	I0,4	8,9	8,5	8,7	5,8	5,2	6,3	II,5	9,3	6,8	[illegible],3
Aldosterone 5--20 µg/days	9,6	I7,3	I6,4	I6,3	I8,4	II,2	3I,8	50,2	27,0	40,3	I2,7	I0,4	8,2	–

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TABLE 2 CONTINUED

I.A.S.

Indices	Preflight, days						Postflight, days							
	- 26	- 25	- 24	- 5	- 4	- 3	0	+ I	+ 2	+ 3	+ 4	+ 5	+ 6	+I0
17-oxycorticosteroids total mg/24 hr 1,31--7,39	II,9	9,72	7,56	7,24	4,67	5,43	5,5	4,67	4,05	6,73	4,56	5,04	5,5I	5,49
Free 1--14%	I9	20	28	II	I5	I0	I2	I2	I3	II	I5	23	I7	I5
Glucuronides 60--80%	54	54	50	77	7I	72	65	58	57	64	62	60	64	67
Sulfates 14--24%	27	26	22	I2	I4	I8	23	30	30	25	23	I7	I9	I8
17-ketosteroids 17-26 mg/24-hr	7,6	5,I	4,4	I0,2	-	4,I	4,8	II,6	5,I	6,9	5,8	9,5	II,2	9,6
Aldosterone 5--20 μg/days	I3,4	I5,2	I7,I	I6,4	I8,4	24,3	32,6	20,9	3I,7	39,0	I9,2	I8,6	I5,3	-

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TABLE 3

	T.A.S.								
	Pre-flight	Postflight, days							
	-25	0	+I	+2	+3	+4	+5	+6	+I0
Epinephrine free 5--15 µg/day	6,4	3I,5	22,3	I9,9	I3,7	I0,6	I2,5	I3,8	I3,3
Epinephrine bonded up to 35 µg/day	I8,7	26,I	39,6	36,4	46,4	39,0	45,6	53,9	38,2
% of bonded Epinephrine, %	392	I89	277	282	439	468	465	49I	385
Free Norepinephrine 20--40 µg/day	I5,0	70,5	37,2	3I,6	20,7	37,2	35,5	38,9	30,6
Norepinephrine bonded up to 50 µg/day	25,0	60,4	I5,9	28,2	45,7	35,7	24,9	28,9	34,0
Percent of bonded Norepinephrine	267	I86	I43	I89	32I	I96	I70	I74	2II
Dofamine free 112--450 µg/day	I65,5	95,I	223	48I	483	375	I89	I84	278
Dofamine bonded up to 500 µg/day	I25,0	88,I	I39,6	I48,I	335,5	232,5	609	306	239,6
Percent of bonded Dofamine	I76	I93	I63	I3I	I69	I62	422	266	I86
DOPA 8-111 µg/day	I2,0	I5,6	25,3	98,7	84,6	86,0	64,0	55,0	7I,8
Metanephrine free 160--190 µg/day	II6	I3I	I38	I45	200	I83	I80	I72	I48
Metanephrine bonded 130--170 µg/day	I02	88	I03	I25	I4I	I33	I30	I25	I3I,9
Percent of bonded Metanephrine	I88	I67	I75	I86	I7I	I73	I72	I73	I89
Normetanephrine free 110--140 µg/day	95	I0I	I09	I29	I44	I5I	I37	I20	I47,6
Normetanephrine bonded 70--90 µg/day	62	54	68	7I	77	80	I03	I00,6	I22,8
Percent of bonded NMN	I65	I53	I62	I55	I54	I53	I75	I84	I82
Vanillyl-mandelic acid 1.9--6.3 mg/day	2,I2	2,5	2,8I	3,40	5,0	5,68	4,20	4,44	4,I0

	K.V.V.								
	Pre-flight	Postflight, days							
	-25	0	+I	+2	+3	+4	+5	[illegible]	[illegible]
Epinephrine free 5--15 µg/day	6,5	30,6	I7,5	I2,0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Epinephrine bonded up to 35 µg/day	25,0	49,2	38,6	28,0	28,7	43,[illegible]	[illegible]	[illegible]	[illegible]
% of bonded Epinephrine, %	484	260	320	322	2II	353	[illegible]	[illegible]	[illegible]
Free Norepinephrine 20--40 µg/day	20,3	7I,6	37,6	38,0	40,0	32,2	26,6	3I,[illegible]	[illegible]
Norepinephrine bonded up to 50 µg/day	2I,6	35,7	57,5	35,8	45,7	4I,I	35,[illegible]	[illegible]	[illegible]
Percent of bonded Norepinephrine	206	I50	253	I94	2I4	228	[illegible]	[illegible]	[illegible]
Dofamine free 112--450 µg/day	275	2I6	549	500	I62	I02,9	I48,[illegible]	[illegible]	[illegible]
Dofamine bonded up to 500 µg/day	I75	I37	I50	308	630	569	497	[illegible]	[illegible]
Percent of bonded Dofamine	I64	I7I	I27	I62	489	653	43I	3II	[illegible]
DOPA 8-111 µg/day	I7,0	40,7	67,3	30,I	88,0	33,I	20,9	[illegible]	[illegible]
Metanephrine free 160--190 µg/day	I27	I28	I80	I99	207	I75	I69	[illegible]	[illegible]
Metanephrine bonded 130--170 µg/day	I00	I0I	II3	I40	I45	I36	I40	[illegible]	[illegible]
Percent of bonded Metanephrine	I79	I79	I63	I70	I70	I78	I83	[illegible]	[illegible]
Normetanephrine free 110--140 µg/day	I09	95	II0	I34	I40	I63	I54	[illegible]	[illegible]
Normetanephrine bonded 70--90 µg/day	63	60	82	89	I0I	I55	[illegible]	[illegible]	[illegible]
Percent of bonded NMN	I62	I63	I75	[illegible]	I72	I96	[illegible]	[illegible]	[illegible]
Vanillyl-mandelic acid 1.9--6.3 mg/day	2,45	[illegible]	2,34	3,00	4,55	4,23	4,[illegible]	[illegible]	[illegible]

TABLE 3 Continued /219

	I.A.S.								
	Preflight	Postflight, days							
	−25	0	+I	+2	+3	+4	+5	+6	+I0
Homovanillic acid 1.6--3.5 mg/day	I,40	I,20	I,88	I,90	2,I0	2,35	3,50	4,00	3,80
E/NE	0,42	0,44	0,59	0,63	0,66	0,28	0,35	0,35	0,43
		I06	I43	I50	I57	68	84	84	I04
NE/DA	0,09	0,74	0,I6	0,06	0,04	0,09	0,I8	0,2I	0,II
		823	I85	73	48	[illegible]	208	234	I22
DA/D	I3,8	I3,7	6,I3	4,87	5,70	4,36	2,95	3,34	3,87
		99	44	35	4I	32	2I	24	28
MN/E	I8,I	4,I5	6,I3	7,28	I4,6	I7,2	I4,4	I2,5	II,0
		23	34	40	80	95	79	69	6I
NMN/NE	6,3	I,43	2,93	4,08	6,95	4,05	3,86	3,08	4,82
		23	47	64	II0	64	6I	49	76
HVA/DA	0,008	I,07	0,008	0,003	0,004	0,006	0,0I8	0,02	0,0I3
		I34	I00	49	54	78	32I	27I	I70
VAA/E + NE	0,I0	0,02	0,04	0,066	0,I4	0,II8	0,08	0,08	0,09
		24,5	II,8	66	I45	II8	87,5	84	93
VAA/MN + NMN	0,0I	0,0I	0,0II	0,0I2	0,0I4	0,024	0,0I9	0,0I5	0,0I4
		I00	II3	I24	I25	242	I90	I52	I38

	Preflight	Postflight, days							
	−25	0	+I	+2	+3	+4	+5	+6	+I0
Homovanillic acid 1.6--3.5 mg/day	I,I0	2,00	2,30	2,44	3,20	3,22	3,50	4,00	3,80
E/NE	0,32	0,42	0,46	0,33	0,64	0,54	0,57	0,48	0,60
		I33	I45	I03	20I	I68	I79	I50	[illegible]
NE/DA	0,07	0,33	0,06	0,076	0,24	0,3I	0,I9	0,I6	0,08
		473	98	I08	352	447	275	230	I20,5
DA/D	I6,2	5,3	8,I5	I6,6	I,84	3,05	7,08	5,69	[illegible]
		33	50	I02	II	I8	44	35	22
MN/E	I9,5	4,I8	I0,2	8,02	I0,I	I0,3	I0,3	I0,3	3,50
		2I	53	4I	52	53	53	53	22
NMN/NE	5,0	I,32	2,9	I0,6	5,42	9,42	9,39	8,49	5,79
		I26	59	2I2	I08	I88	I88	I69	II6
HVA/DA	0,004	0,009	0,004	0,006	0,0I9	0,04	0,03	0,02	[illegible]
		230	I00	I50	493	I027	807	590	352
VAA/E + NE	0,09	0,0I7	0,042	0,059	0,069	0,086	0,I06	0,099	0,0I7
		I8,8	46,6	65,5	76,6	94,4	II6	II0	I30
VAA/MN + NMN	0,0I	0,008	0,008	0,0I2	0,0I3	0,0I2	0,02I	0,0I6	0,02
		80	80	I28	I3I	I25	2I5	I60	20I

Indices	K.V.V.			I.A.S.			Boundaries of the standard
	Pre-flight	Postflight, days		Pre-flight	Postflight, days		
	– 27	+ I	+ 25	– 27	+ I	+ 25	
Glucose mg%	82,0	85,32	84,37	86,7	86,26	I26,56	60 – I00
Lactate mg%	25,7	8,I0	36,79	2I,4	7,48	[illegible]4,I0	9 – I6
Pyruvate mg%	I,58	0,5I	0,09	I,82	0,596	[illegible],53	0 – I,2
Total lipids mg%	I3I0	925	720	I520	860	770	400 – I000
Triglycerides mg/%	87,4	96,6	I03,7	75,3	6I,I	82,4	72 – I74
NEFA meq/l	220	458	862	300	659	500	90 – 600
Lactate dehydrogenase Med/ml	I48	I74	I96	I73	I56	I75	I20 – 240
Isoenzymes LDH (%)							
LDH1	33,6	24,9	I9,3	30,3	23,7	22,4	20 – 30
LDH2	36,6	40,7	44,I	36,2	36,7	50,3	30 – 50
LDH3	I6,5	I6,9	22,0	2I,I	23,2	2I,	I0 – 20
LDH4	II,I	8,9	8,8	9,9	9,3	4,3	2 – I0
LDH5	2,2	8,6	5,8	2,5	7,I	I,5	0 – 8
Malate dehydrogenase Med/ml	66,0	5I,6	82,5	74,3	33,0	66,0	48 – 96
Isoenzymes MDH (%)							
MDH1	32,3	24,5	22;8	22,4	20,6	23,9	I2 – 30
MDH2	23,6	27,5	24,6	29,9	3I,9	28,8	20 – 40
MDH3	44,I	48,0	52,6	47,7	47,5	47,3	40 · 60
Isocitrate dehydrogenase Med/ml	3,54	4,[illegible]	3,54	2,36	6,7	I,97	less than 7
α-oxybuterate dehydrogenase Med/ml	74,I	98,8	86,4	87,5	98,8	89,5	less than I40
Creatine phosphokinase Med/ml	I9,8	20,7	I9,0	25,0	60,0	25,9	less than 50
Alkali phosphatase Med/ml	75,9	87,4	II8,8	77,5	74,2	I58,4	60 – I70
Alanine amino transferase Med/ml	I0,0	I2,3	II,4	8,6	I3,3	II,4	less than 22
Aspartate amino transferase Med/ml	9,7	II,4	8,9	9,7	I3,3	I0,5	less than I8

characterized in I.A.S. by an increased level of STH in the blood in comparison with the preflight values with practically unchanged content of insulin, where in K.V.V., the level of insulin noticeably increased (by 1.7 times) and on the first day, exceeded the normal with an unchanged concentration of STH in this period, with a decreases /201 of the content of these hormones by the 25th day after landing.

On the 1st and 25th days after landing, in K.V.V. one observed a significant decrease in the level of testosterone in the blood, whereas in I.A.S. the content of this hormone on the 1st day somewhat exceeded, and on the 25th day was less than the preflight value.

In the perflight period, in both cosmonauts a low level of cAMP and cGMP in the blood was detected, less than the normal value. On the 1st day of the readaptation period, the level of these compounds significantly increased (to normal values) with its subsequent increase on the 25th day of the readaptation period in both cosmonauts.

When studying the concentration of PG, the following was noted. Before the flight in both cosmonauts the level of PG A + E, significantly exceeding the normal. The postflight period examination in both cosmonauts was characterized by a sharp decrease (less than normal) of these compounds, particularly pronounced on the 25th day. As to the PG of the F group, the preflight level of PG F_1-α was at the lowest boundary of the normal in K.V.V. and exceeded the normal in I.A.S., and the level of PG F_2-α was lower than the normal value in both cosmonauts. In the postflight period, the level of PG F_1-α, also, like the content of PG A + E, was decreased on the first day lower than the normal in the cosmonauts; however on the 25th day there was an increase to normal values. The level of PG F_2-α in both cosmonauts in both periods of postflight examination was noticeably lower than normal and preflight values.

The study of removal of corticosteroid hormones with the urine (Table 2) showed that excretion of total 17-OCC in I.A.S. for days 26--24, and in K.V.V. on the 25th day before launch of the spacecraft, noticeably exceeded the usually adopted standard with simultaneous increase in the percentage content of free forms and sulfates of 17-OCC in the urine. Then, excretion with the urine of /204 17-KS in both cosmonauts for days 26--24 preflight and in I.A.S. on day 3 before launch were lower than the lowest normal boundary.

The entire period of readaptation in I.A.S. was characterized by a somewhat decreased (in comparison with preflight) excretion total 17-OCC whereas on the day of landing and in the first 3 days, the percent of free forms and glucuronides given off was lower and sulfates higher than the preflight level. Beginning with the 4th day of the postflight period, excretion of free 17-OCC increased, exceeding the normal and close to the value noted preflight. Somewhat different dynamics of change in the indices postflight were noted in K.V.V. Thus, on days 0, 1 and 4 of the postflight period, a significant increase was noted in excretion of total 17-OCC and glucuronides, exceeding both the normal and values found preflight whereas giving off free forms and sulfates was significantly lower than normal and preflight values. The entire remaining postflight period was characterized by a certain decrease in excretion of total 17-OCC in comparison with the preflight whereas the generation of free 17-OCC increased, exceeded the normal and was found at the preflight level; then, generation of sulfates mainly was lower than the preflight level.

Excretion with the urine of 17-KS in the postflight period in both cosmonauts hardly differed from the preflight although on days 0, 4 and 5 in K.V.V. and on days 1, 5, 6 and 10 in I.A.S. they were characterized by a certain increased level of excretion of 17-KS up to the normal values.

Excretion of aldosterone from the urine in both cosmonauts in the preflight period was within limits of the generally adopted norm (except for an increase on day 3 before launch in I.A.S.). Generation with the urine of the hormones on day 0 and the first /205
3 days of the postflight period significantly increased, exceeding both the normal values and the values perflight. The entire subsequent period of readaptation was accompanied by a decrease in excretion of aldosterone to the perflight values.

The changes noted in the preflight period in the content of hormones studied and the biologically active compounds in the blood and urine in the cosmonauts, in comparison with the generally adopted normal, could be the result of a reaction of the organism to different tests and loads during the clinical and physiological examination of the cosmonauts, and also as a result of emotional stress caused by preparation for the flight. The increase in activity of renin in the plasma and concentration of aldosterone in the blood was noted during emotional stress [24]. We also showed in the experiment with emotional stress an increase in activity of renin in the blood plasma. Similar results were obtained in K.V.V. and I.A.S. during examination before the flight.

The postflight changes of activity of plasma renin and the content of aldosterone in the blood and urine were obviously directed at maintaining the water-salt balance of the organism in the cosmonauts.

One should turn attention to the character of changes of STH and insulin levels in the blood in the cosmonauts. For instance, on the first day postflight in K.V.V. one noted an increase in the concentration of insulin with an unchanged level of STH and in I.A.S., an increase in the STH level was not accompanied by changes in the concentration of insulin. The changes noted, in all probability, involve a certain restructuring of the processes of lipid, protein and carbohydrate metabolism.

The readaptation period in both cosmonauts was accompanied by a decreased level of testosterone which, in all probability, was the reason for hyperglyceridemia discovered in the cosmonauts.

An analysis of the data on content of TTH and T_4 and the value /206 of CET showed the individuality of these changes. At the same time, the level in the blood of the biologically more active hormone of the thyroid gland, T_3, decreased in both cosmonauts. The increased level of cortisol in the blood which we discovered in the cosmonauts is the possible cause of a lower level of T_3. On the other hand, it is well known that lengthy injection of glucocorticoids suppresses the thyroid function, obviously, by inhibition of TTH which finally causes a decrease in the content of T_4. As is well known, excretion of cortisol with the urine during space flights increases [25, 26]. This can result , besides an increase in the level of cortisol in the blood, in a decrease of the level not only of T_3 but also T_4. This, in our opinion, can explain the fact that the level of T in K.V.V. was decreased.

As was pointed out earlier, the content [illegible] TTH and T_4 in the blood in cosmonauts who had completed a 7-day cosm[illegible]ht, basically increased with the simultaneous increase in [illegible]vel of T_3 in the blood [27] at the same time that after comp[illegible] of long-term space expeditions, the content of T_3 in the [illegible] decreased and the level of TTH and T_4 decreased differently [[illegible] In all probability, the changes noted in level of T_3 in the blood depends on the duration of the spaceflight.

The decreased level of cyclic nucleotides (cAMP and cGMP) and PG of the pressor group (F_2-α) with a simultaneous increased content of PG of the depressor group (A +E) in the cosmonauts in the preflight period can be evidence of a certain decrease in sensitivity of the vessels to sympathetic and pressor effect [29], in particular, epinephrine which is confirmed by the data we obtained on excretion of free epinephrine whose level is found in the cosmonauts at the low boundary of normal.

After flight (day 1) one noted a significant decrease (below the /207
normal) in the level of PG in all groups in both cosmonauts which can be evidence of a decrease of the regulatory effect of these compounds on the vascular tone. The significant increase discovered in the level of cyclic nucleotides during the entire period of readaptation with simultaneous further decrease in the concentration of PG A + E and an increase in the level of PG F_1-α on day 25 postflight can cause an increase in vascular tone. The changes indicated can also be the result of emotional stress.

The studies of the generation of 17-OCC with the urine showed a directionality of the secretory activity of the adrenal gland cortexes in both cosmonauts in the preflight period; the increased (beyond the normal limits) percentage content of free forms of 17-OCC is evidence of this. Excretion with the urine of total 17-OCC then was observed either at the upper boundary of normal or in a number of cases exceeding it. At the same time, in this period one noted a decrease in the content of glucuronide and sulfates in the urine; this could be evidence both of changes between processes of secretion and conjugation of steroids, and changes in the processes of their catabolism [30]. The decreased level of excretion of 17-KS in both cosmonauts, lower than the normal value, can be the result of change in metabolisms of steroid hormones along the 17-keto path.

In the postflight period (on days 0--2) one noted an increase in the processes of conjugation of steroids with glucuronic acid; the decrease in free forms and sulfates and the increase in glucuronides in the urine are evidence of this. And by days 3--4, one observed an increase in the secretory processes of the adrenal gland cortex (an increase in free forms of 17-OCC and a decrease in glucuronides in the urine). One should note that excretion of total 17-OCC with the urine in the period of readaptation basically is at the level of the preflight values. We were the first to observe this dynamic of generation of total 17-OCC with the urine. The data we obtained earlier [1, 27] showed a noticeable increase in this index in the /208 cosmonauts in the postflight period; this is evidence of the presence of a state of stress. In this way, after completion of a 140-day spaceflight, taking into account that the steroid hormones are one of the indicators of stress, we discovered the so-called "stress re-adaptation ."

The set of data obtained when studying the content of hormonal and biologically active compounds in the blood and urine indicates that after completion of a 140-day space expedition, in both cosmonauts, certain changes were noted in the state of the basic regulatory systems including an increase in functional activity of β-cells of the islands of Langerhans of the pancreatic gland. Moreover, in the postflight period in both cosmonauts, a certain decrease occurred in the activity of the renin-angiotensin-aldosterone system accompanied by an increase in excretion of aldosterone with the urine. One should note that there was a direction in changes of secretion and excretion of hormones and biologically active compounds in the cosmonauts who had completed a 96-day spaceflight, however, after a 140-day spaceflight, in distinction from the 96-day, no increase in excretion of total 17-OCC with the urine was detected but changes in secretory activity of the adrenal gland cortex had a phase character. Moreover, an increase in content of cyclic nucleotides was noted in the blood with a significant decrease in concentration of prostaglandins of all groups.

Analyzing the data which characterize activity of the sympato-adrenal system (Tables 1, 3) one can see that preflight the activity of SAS in both cosmonauts was within limits of the physiological norm. In spite of a somewhat decreased excretion (in comparison with the generally adopted norms) the CA and their metabolites with the urine, the indices of relative activity of CA exchange were within /211 the limits of their physiological variations.

On the first day after completion of the flight, the content of CA in the blood in both cosmonauts was significantly higher than the preflight level. On day 25 of the postflight period, the content of CA 'n the blood had a tendency toward decrease in comparison with the p. ding time period for observation, but remained always higher than the preflight values. The ratio of E/NE (according to one blood system) was in both time periods of postflight examination lower than the preflight value which indicated a predominance of activity of the mediator link of SAS in comparison with the hormonal.

On the day of landing (day 0) we observed a significant increase in the excretion of E, NE, DOPA, MN, VAA and HVA with the urine in comparison with the preflight values in both cosmonauts whereas both excretion of DA and NMN, on the other hand, were decreased. The ratio of E/NE (according to the urine data) in K.V.V. was insignificantly increased in comparison with the preflight level; in the I.A.S. it was found at the level of the initial values. The percentage of bonded E was below the preflight like the process of methylation of E (MN/E) in both cosmonauts. The relative activity of synthesis of NE was significantly increased in both cosmonauts whereas in K.V.V. it amounted to 473% and in the I.A.S.--823% of the preflight level. The relative acitivity of synthesis of DA was, on the other hand, decreased in both cosmonauts and the percent of bonding of NE in both cosmonauts was below the preflight level; the process of methylation of NE (NMN/NE) in I.A.S. was decreased and in K.V.V. it was insignificantly increased. The processes of deamitization of CA (VAA/MN + NMN) in I.A.S. were found at the level of preflight values and in the K.V.V it was decreased, amounting to 80%. The process of inactivation of VA (HVA/DA) in the I.A.S. was slightly increase and in K.V.V. it was lower than the initial.

Thus, on the day of landing, in both cosmonauts, there was no increase in the activity of the SAS hormonal link which is evidence /212 probably of an absence of a stress reaction of the organism when returning the cosmonauts to Earth.

In the succeeding period of examination of excretion of E in both cosmonauts, there was a tendency toward a decrease although it still exceeded the preflight level. The percentage of bonding of E in I.A.S. was higher and in K.V.V. lower than the initial values. The process of methylation of E (MN/E) in both cosmonauts is lower than the preflight. The excretion of NE, DA, DOPA, MN, NMN, VAA and HVA for the extent of the postflight examination period, in both cosmonauts, was higher than the preflight vlaues. The ratio of E/NE exceeded the preflight level on days 1--3 of the postflight period in both cosmonauts and then one observed a decrease in this index below the initial values. The relative activity of synthesis of NE (NE/DA) had a tendency toward a decrease up to the 4th day of the readaptation period and then again an increase was observed in both cosmonauts. The percent of bonding of NE in I.A.S. was below the preflight level and in K.V.V. on the other hand, was higher. The process of methylation of NE (NMN/NE) in I.A.S. was lower and in K.V.V. higher in comparison with the initial. The processes of deamination of CA in both cosmonauts was increased for the entire period of the postflight examination. The relative activity of DA synthesis (DA/D) was decreased for the entire extent of the readaptation period in both cosmonauts in comparison with the preflight level and the process of inactivation (HVA/DA) also, like the percent of bonding of DA was lower in I.A.S. and on the other hand, higher in K.V.V.

Thus, in the postflight period in both cosmonauts an insignificant increase was observed in the activity of the hormonal link of SAS which, probably, involved an emotional reaction caused by the conduct of certain measures in the postflight period. One should note that /213 we were the first to observe an absence of a stressor reaction on the landing day. The data we obtained earlier [31] when examining cosmonauts after flights of shorter duration indicated the presence of stress reactions in them. American scientists who studied the state of SAS in astronauts who had completed a flight on the Mercury, Gemeni, Apollo spacecraft also obtained activation of the hormonal link of SAS after completion of flights [32--36]. Some authors [33, 37] considered the change in activity of SAS as an index of the "stress" reaction caused by the conduct of space flight. The data we obtained, however, agree with data of American scientists who had studied the state of SAS in the astronauts on the Skylab OS [37, 38] where also it was pointed out that space flights of longer duration did not cause significant changes in the state of SAS and facilitates creation of adjustment and adaptation mechanisms to a new living circumstance which space flight is.

The activation of the mediator link in SAS which we observed in both cosmonauts occurred with a different differentiation of the processes of exchange of CA. Thus, while in the I.A.S., the process of increasing relative activity of synthesis of NE occurred on a background of decrease of processes in its bonding and inactivation, but K.V.V. showed an increase in the process of inactivation of NE on a background of decreased relative activity of synthesis of DA which occurred in both cosmonauts.

In this way, the increase we obtained in activity of the mediator link of SAS in the cosmonauts was, probably, due to their return to normal conditions of gravitation and the differences observed in the metabolism path of CA, then, apparently, are due to individual reaction of the organism of the cosmonauts.

Determination of the content in the blood of the basic metabolytes /214
of carbohydrate, fat metabolism and also activity of a number of enzymes (Table 4) indicated that on the 1st day after completion of flight, only insignificant changes were noted in the biochemical indices studied in comparison with the data of background examination.

In both cosmonauts a decrease occurred in the concentration in the blood of lactic and pyruvic acids, the total lipids and triglycerides, whereas the content of NEFA noticeably increased (in I.A.S it was slight higher than the physiological norm). However one should note that the preflight level of content of lactate, pyruvate and total lipids in the blood somewhat exceeded the value of the generally adopted norm. Similar deviations in indices of carbohydrates and fat exchange from the level of the physiological norm was noted earlier by us in background examinations immediately before beginning the expedition and in other cosmonauts (crews of the Soyuz-26, 27, 28 spacecraft). Here, the increased content of total lipids in the blood, as a rule, is not accompanied by an increase in concentration of actively metabolized fatty fractions which are the energy substratum, NEFA and triglycerides. Possibly the increased level of total lipids is due to an increase in the content of phospholipids and cholesterol in the blood. The cause of functional hypercholesterinemia can be, for example, different stresses, physical and emotional which the cosmonauts underwent in the period of conducting clinical and physiological studies. In the opinion of many reserachers, the most frequent cause for increase in content of lactate and pyruvate in the blood also is an increase in physical load [39].

The activity of enzymes of the blood changed within limits of normally allowable variations. In both cosmonauts, an increase in activity of ICDH, α-OBDH, AST, ALT, CPK (CPK in I.A.S. exceeded the limits of normal activity) and a decrease in total activity of MDH occurred in both cosmonauts. The direction of changes in LDH activity, its isoenzymes and AlP was nonuniform in the commander and flight engineer; in K.V.V. an increase occurred in total activity of LDH as a result of activation of the LDH_2 and LDH_3 fractions; in I.A.S. a decrease was noted in activity of LDH accompanied by a significant increase in activity of the LDH_5 fraction; AlP was somewhat decreased in I.A.S. and increased in K.V.V. /216

During an examination made on the 25th day of the postflight period, a significant increase was established in the content of lactate in the blood in both cosmonauts (in K.V.V. it significantly exceeded the boundary of the norm) and glucose in I.A.S.; the concentration of NEFA in the blood remained increased whereas in K.V.V. it exceeded the limits of normal values and the concentration of triglycerides increased. The activity of most of the enzymes studied in the blood on the 25th day reached a level close to the initial; only when determining AlP did one detect activity significantly exceeding the initial. An analysis of the isoenzyme spectrum of AlP in the blood showed that an increase in the total activity of AlP occurs due to an increase in concentration of the bone isoenzyme and is due, apparently, to activation of the processes of mineralization in the boney tissue.

Analyzing a change in biochemical parameters of the blood observed in the cosmonauts after completing the 140-day flight, one can see that due to factors of space flight only an insignificant restructuring of the basic exchange processes occurred, physiologically based on the necessity for maintaining homeostasis in unusual conditions of space flight. No pronounced disturbances in exchange of substances was established. In the first days after landing, a tendency was clearly noted toward a change in the ratio of basic paths of metabolism /217
expressed in the primary use energetically of more suitable oxidation conversions of fats. The basis for this conclusion is data on the sharp increase of intermediate products of carbohydrate exchange entering the blood, lactate and pyruvate, increased ejection into the blood channel of NEFA and a significant decrease in content of total fats. Data on the increase of such enzymes in the blood as α-OBDH and, to a large degree, ICDH also agree with this conclusion on strengthening of the oxidation processes; the rate of oxidation conversions of the substrata in the cycle of tricarbonic acids depends to a signigicant degree on this activity. One should note that this conclusion and also data it is based on do not coincide with results obtained during biochemical studies of cosmonauts after completing the 96-day spaceflight. On the basis of an increase in substrata of the carbohydrate exchange, decrease of neutral fats and NEFA entering the blood, and also changes in the blood of certain exzymes of aerobic exchange and glycolysis, we concluded that there was an increase in specific weight of anaerobic processes in the total energy reactions of the organism in the first days after completion of the 96-day flight.

TABLE 1. OUTPUT OF FLUID (ML) AND ELECTROLYTES (MEQ) WITH THE URINE ON THE DAY BEFORE AND AFTER FLIGHTS IN THE CC-I, FE-I, CC-II, FE-II /219

	Diuresis	Sodium	Potassium	Calcium	Magnesium
CC-I Preflight	I470±94	202±I2	85±5,4	9,8I±I,5	8,3±I,3
Postflight					
"0" day	II75	I84	45	I3,2	7,I
"I st day	II30	I99	8I	I6,4	9,0
2 nd day	I4I5	I28	87	I4,I	6,9
3 rd day	I645	2I4	99	I2,8	6,6
4 th day	I990	297	II5	I7,5	I0,9
5 th day	I235	22I	93	I8,0	9,5
FE-I Preflight	II32±I02	242±26	75±4,0	I5,7±0,3	6,9±0,2
Postflight					
0 day	425	67	23	22,5	3,8
I st day	II75	I35	73	23,5	I0,4
2 nd day	I285	I49	62	I8,0	8,0
3 rd day	2I05	282	II2	22,I	7,7
4 th day	I770	206	87	I8,6	8,0
5 th day	I0I5	I88	98	I3,0	7,2

[Commas in tabulated material are equivalent to decimal points]

TABLE 1. continued

/220

	Diuresis	Sodium	Potassium	Calcium	Magnesium
CC-II Preflight	930±46	I82±5,3	76±7,4	I2,0±I,0	I0,3±0,7
Postflight					
0 day	I225	73,5	63	I4,9	2,7
Ist day	I255	25,4	82	6,3	4,0
2nd day	I440	274	I85	5,I	4,6
3rd day	2745	706	I20	I0,0	7,8
4th day	I480	402	I05	8,9	9,8
5th day	620	I59	52	9,4	8,6
IIth day	I675	228	77	9,8	8,5
FE-II Preflight	II20±98	I85±I5	79±8,5	I4,4±I,4	I2,8±0,9
Postflight					
0 day	705	II4	30,3	II,3	3,0
Ist day	745	60	47,2	23,I	8,I
2nd day	I220	I34	89	I7,7	8,I
3rd day	I550	I40	90	I6,9	6,8
4th day	II65	I87	I28	I7,5	I2,2
5th day	I230	I78	89	I8,5	I0,2
IIth day	960	220	54	I4,4	II,0

[Commas in tabulated material are equivalent to decimal points]

The different results obtained immediately after completion of the 96-day and 140-day flight are not random. They can be explained by the phase character of the processes of adaptation of the organism to conditions of spaceflight. Apparently, the moment of completion of the 96-day and 140-day flights occurs at different stages of this adaptation. In spite of the fact that the character and course of the readaptation processes, according to the data of biochemical analysis, was similar in mombers of the crew of the two long-term space expeditions. Almost complete normalization of metabolic homer-stasis was noted by the 25th day (second main expedition) and on the 32nd day (first main expedition) after completion of the spaceflight.

4.2. Study of the Water-salt Exchange and the Functional State of the Kidneys /218

Method

The state of the water-salt exchange was evaluated according to the content in blood and urine of electrolytes of sodium, potassium (flame photometry), calcium and magnesium (atomic absorption spectro-photometry) and osmotically active subtances (cryoscopy). Urine before and after the flight was collected according to fractions. For studying the peculiarities of osmoregulatory and ion regulatory functions of the kidneys before and on the second day after both flights, specific load tests were done. During the 96-day flight, a water test was used (2% of body weight) and during the 140-day flight, a water-calcium test was used (peroral introduction of calcium lactate, 10/mg/kg body weight on a background of 1% water load). Besides the study of the absolute values of generation of fluid and electrolytes by the kidneys, determination of the values of those substances entering with the food and in the form of drinks was determined. For this purpose, tests of the food ration were minimized by a method of dry calcination and their electrolytic composition was studied. The value of the percent of kidney excretion of fluid and electrolytes made it possible to judge the correspondence of substances taken in with food and their elimination from the kidneys. In the blood serum, besides the concentration of electrolytes and osmolarity, activity of the calcium ions was determined by a method of direct potentiometry using an ion selective film electrode on a base of teno-ultrafluro-acetate.

Excretion by the kidneys of fluid immediately after landing in both cosmonauts, except CC-II, was decreased (Table 1). On a back-ground of decreased diuresis in CC-I, FE-I and FE-II, the water demand increased which was the cause of a significant decrease in the value of the percent of kidney excretion of fluid. In the CC-II in the first 2 days after landing, diuresis was also somewhat higher than preflight. The cause for this was a decrease in reabsorption of /221 water in the distal section of the nephron which was confirmed by a decrease in the value $T^C_{H_2O}$. The peculiarities noted in water exchange, immediately after landing, in the CC-II to a significant degree could due to the fact that he, in distinction from the other cosmonauts, did not take the water-salt additive in the final stage of flight.

When studying exchange of electrolytes it was established that in all the cosmonauts after landing one noted a decrease in the rate of excretion of sodium (Table 1). The CC-II had a particularly pronounced retention of sodium. The concentration in the urine and generation of potassium by the kidneys in the CC-II then was only insignificantly below the initial values; due to this, the value of the coefficient Na/K significantly decreased. In the CC-I, FE-I and FE-II, the rate of excretion by the kidneys of potassium on day 0 after landing was significantly smaller than in the background period (Table 1). On succeeding days of the observation, the absolute values of generation of potassium increased, not differing significantly from the preflight level. However, in comparison with the value of potassium, supplied in the food ration, its generation was above the initial. A similar phenomenon was observed in a number of cosmonauts in the period of background examination. However, it was not accompanied by an increase in excretion of products of nitrogenous exchange and was reevaluated by us as a result of high physical and emotional stress. During flight, the increased excretion of potassium was combined with increased generation of nitrogen; this was evidence of the predominance of processes of catabolism during long stays in weightlessness [40, 41]. At the present time it is considered generally known that the negative balance of potassium in conditions of space flight is caused by a decrease in cellular mass. Due to this, only with the degree of increase of physical load in the postflight period are the ordinary interactions reestablished between intake and output of potassium. In this case, it becomes obvious /222 that it is necessary to reestablish the balance of potassium by increasing its intake. Even with an undisturbed regulation of potassium, at a cellular level, its assimilation is difficult before restoration of the cellular mass of the body adequate for the increased requirement by the organism.

Output of potassium by the kidneys in both cosmonauts after the 96-day flight was higher than the preflight values. No peculiarities in excretion of magnesium were noted (Table 1). After the 140-day flight, excretion by the kidneys of 2-valent ions in the CC-II during the first 3 days was significantly lower than the initial level. On subsequent days, output of potassium and magnesium in the CC-II was somewhat increased. Considering that the intake of potassium with the food after flight also was lower than the background values, the percent of excretion of it by the kidneys did not differ from the initial level. In contradiction to this, in the FE-II, output of potassium by the kidneys from days 1 to 6 after flight was higher than the initial and reached background values only on day 11 postflight examination. One should particularly note that the increase in excretion of potassium occurred in spite of an intake from food smaller than preflight. Due to this, the percent of its excretion in the FE-II was increased to 34--44% with the initial--27%. Output of magnesium in the FE-II on days 1--4 of the examination remained decreased and subsequently did not differ significantly from the initial.

During an analysis of blood serum in all cosmonauts postflight, an increase was established of the ionized fraction of potassium.

No other significant changes were discovered in the content of electrolytes and osmotic concentrations of blood serum after the 140-day flight.

Water Tests Before and After the 96-day Flight

In the CC-I, output of fluid after the water load postflight did not change significantly. One should remember that afer the 30-day flight, in the FE-I the output of fluid with the water tests /223 was more than two times lower than the initial [42]. The value of maximum diuresis after load in both cosmonauts was higher than in the preflight period and to a greater degree in the FE-I (Table 2).

TABLE 2. WATER LOAD TEST BEFORE AND AFTER FLIGHT IN THE CC-I and FE-I: I--MAXIMUM RATE OF EXCRETION OF FLUID (ML/MIN) AND ELECTROLYTES (μEQ/MIN); II--OUTPUT IN THE FLUID TEST (PERCENT OF INTAKE) AND ELECTROLYTES (MEQ)

/224

			Diuresis	Sodium	Potassium	Calcium	Magnesium
CC-I	Preflight	I	I4,0	II2	74	4,9	2,38
		II	90%	20,8	I4,0	0,67	0,38
	Postflight	I	I5,2	II9	3I	I9,I	7,36
		II	76%	I7,6	6,23	3,I5	I,2I
FE-I	Preflight	I	I2,8	227	95	5,8	I,9
		II	83%	2I,I	II,6	0,69	0,32
	Postflight	I	22,3	283	I29	25,9	7,I4
		II	I08%	2I,0	I6,8	3,25	I,0I

[Commas in tabulated material are equivalent to decimal points]

The direction of changes of excretion of sodium and potassium during the water test in the postflight period also had individual differences. In the CC-I, in comparison with the preflight data, one noted a certain decrease in excretion of sodium and a significant decrease in excretion of potassium. In the FE-I, excretion of sodium remained unchanged and potassium increased. Due to this, the value of the coefficient of Na/K for water load in the CC-I increased from 1.5 to 2.8 and in the FE-I decreased from 1.81 to 1.25. Also practically the directionality of the changes in excretion of the substances indicated was apparent in the period of maximum diuresis (Table 2). The individual differences manifested in the cosmonauts in the output of fluid and sodium in the water test is due, apparently, to the peculiarities of osmoregulation and volume regulation. /223

Besides the varied changes noted in excretion of fluid and univalent ions during the water test unitypical shifts were apparent in output of calcium and magnesium. In all of the parts of the urine postflight, the rate of excretion of 2-valent ions in both cosmonauts was higher than in the test conducted preflight. The difference consisted in the fact that in the CC-I the cause of this phenomenon was an increase in concentration of ions and in the FE-I--to a greater degree a change in diuresis.

Changes in the exchange of calcium after long-term flights deserves special attention. An increase in the rate of excretion of calcium and magnesium were observed after less lengthy flights including in the FE-I after a 30-day flight [42]. However, with an increase in length of the flights, the rate of excretion of calcium and magnesium during the test increased to a greater degree. Thus, if after a 30-day flight in the FE-I output of calcium and magnesium /225
during the test with water load exceeded the initial level by 2.5 times, then afer the 96-day flight excretion of calcium was higher than in the background period by 5 times. Here, after a 30-day flight excretion of magnesium increased to this degree and the value of the coefficient Ca/Mg remained practically the same as preflight. After the 96-day flight, to a greater degree, excretion of calcium increased. The value of the Ca/Mg coefficient then increased with 2.2 in the background and 3.2 postflight. The role of the kidneys in changes of calcium exchange during long-term flights was studied using a specific load.

Water-calcium Test Before and After the 140-day Flight

After the flight, in both cosmonauts, one not a progressive increase in the rate of excretion of calcium by the kidneys, reaching a maximum value during the 3rd hour after introduction of calcium lactate. The increase in the rate of excretion of calcium with the urine in both cosmonauts postflight significantly exceeded the preflight level (Table 3). Comparing the data of postflight examination with the results of the ground experiments, one should note that postflight, the increase in rate of excretion of calcium with the urine in both cosmonauts significantly exceeded the preflight level (Table 3).

TABLE 3. WATER-CALCIUM LOAD TEST BEFORE AND AFTER FLIGHT IN THE CC-II AND FE-II: I--MAXIMUM RATE OF EXCRETION OF ELECTROLYTES (μEQ/MIN), II--OUTPUT OF ELECTROLYES IN THE TEST (MEQ)

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			Sodium	Calcium	Magnesium
CC-II	Preflight	I	I98	I8,4	8,95
		II	39,5	4,63	2,26
	Postflight	I	I06,6	4I,6	8,68
		II	I5,0	5,02	2,42
FE-II	Preflight	I	3I8	25,2	I0,6
		II	86,I	5,55	2,40
	Postflight	I	208	74	I0,3
		II	57,5	7,8	2,7

[Commas in tabulated material are equivalent to decimal points]

Comparing the data of postflight examination with the results of the ground experiment, one should note that postflight the increase in rate of excretion of calcium with the urine was significantly greater than during the 182-antiorthostatic hypokinesia (ANOH). When examining the cosmonauts, a study was not made in the blood of concentrations of calcium and its ionizing fraction in the period of the maximum rate of excretion of calcium as was done in the ANOH; this made it difficult to calculate the indices of the calcium-urethral function of the kidneys which reflect transport of this ion in the kidney. However, similarly to the ground experiment, one can assume that the increase in excretion of calcium was caused, basically, by a decrease in reabsorption of it in the kidney channels. The more pronounced increase in excretion of calcium in the FE-II, probably, was mainly due to its individual peculiarities apparent in the high rate of excretion of calcium both in the daily urine and under the load test. Apparently, as in the ground experiments, the most important reason for shifts in exchange of calcium during long flights is a change in its hormonal regulation. An increase in activity of PTG noted in conditions of ANOH occurs first and facilitates, probably, /225 /227 an increase in resorption of boney tissue and an increase in activity of calcium in the blood which, in turn, can be the cause for an increase of thyrocalcitonin in the blood causing a decrease in reabsorption of calcium in the kidney canals. Making the mechanisms which produce changes in calcium exchange more precise is the object of further multidirectional studies.

For evaluating activity of the kidneys during flight, the cosmonauts regularly underwent clinical analysis of urine. Moreover, the visitors delivered samples of urine from the expeditions for more detailed analysis of them on Earth. Here no pathological changes were detected in the urine.

On the basis of the studies made, one can assume that the shifts noted during and after the 96-day and 140-day space flights in water-salt exchange are due not to a disturbance in activity of the kidneys but are the result of changes in the state of these systems which regulate osmotic and ion homeostatis in weightlessness and with reentry into Earth's gravitation.

4.3. Hematolytic Studies /228

Method

The material for the study was peripheral blood taken from the fleshy part of the finger (days 0) and the ulnar vein (days 1, 27 postflight). The results obtained were compared with the results of background examinations of the cosmonauts. Blood from the finger for the biochemical studies in flight was taken on the following days: on days 48 and 89 from the MC-I and on days 18, 75 and 123 from the MC-II. An analysis of the test was made in the laboratory upon return to Earth. In the blood samples taken before, during and after flight, the content of the following substances was defined: glucose (according to the glucose oxidase reaction in the presence of phenophthalein), urine (according to the reaction with urease), nitrogen amine (Nesslerization after preliminary distillation of generated ammonia), acid soluble and lipid inorganic phosphorus (according to the reaction with malachite green in the presence of ammonia molybdate), nucleotides (according to absorption in the ultraviolet field), cholesterol (according to the reaction of acetic anhydride and sulfuric acid), hemoglobin (according to absorption of a thinned solution of blood at 400 nm). The results obtained were calculated for weight of blood taken and its dry residue.

When conducting a study on the state of the blood system, methods of scanning microscopy were used, a photometric analysis of volume indices of erythrocytes, methods of analytic and preparatory electrophoresis of the blood cells, light microscopy. The structure of hemoglobin and its oxygen-transport function was studied by methods of isoelectrofocussing, electrophoresis and column chromatography, spectrophotometric analysis. The indices of exchange of iron were evaluated on the basis of determining concentrations of serum iron

TABLE 1. RESULTS OF STUDYING CERTAIN BIOCHEMICAL INDICES OF THE BLOOD IN MC-II CREW MEMBERS BEFORE, DURING AND AFTER FLIGHT

Indices		Preflight 6.09 1977r	2.10 1977r	12.10 1977r	4.12 1977r	28.12 1977r	8-11.06 1978r	3.07. 1978r	29.08 1978r	16.10 I[illegible]r	3.11. 1978r
Urea, mg/%	CC-II	38,0	35,6	-	26,2	40,5	28,5	43,0; 43,0	40	4I	23
	FE-II	33,5	3I,0	-	24,4	3I,2	I9,5	48,5; 48,0	45	40	20
Nitrogen amino acids mg/%	CC-II	-	-	-	-	-	7,2	4,6; 5,6	-	-	-
	FE-II	-	-	-	-	-	7,0	I3,9; I3,6	-	-	-
Glucose, mg/%	CC-II	75	82	8I	80	65	50	50; 56	85	45	52
	FE-II	75	72	-	85	75	50	78; 57	-	65	68
Inorganic phosphorus mg/%	CC-II	2,8	3,4	3,2	3,0	3,3	3,5	-	4,5	2,6	2,0
	FE-II	2,7	3,8	-	3,3	3,9	4,5	-	5,5	2,9	2,7
Acid soluble phosphorus, mg/%	CC-II	26,0	27,0	28,0	20,0	-	23,5	-	I8	I7	I8
	FE-II	-	-	-	20,0	-	20,0	-	20	I6,5	I5
Nucleotides, mol/l	CC-II	0,9	0,98	0,96	0,92	I,0	0,88	0,86; 0,96	-	0,83	0,88
	FE-II	0,94	0,9	-	0,94	0,92	0,83	I,08; I,02	-	0,95	0,72
Lipid phosphorus mg/%	CC-II	I0,0	II,8	II,4	II,4	I0,6	I0,0	9,0; I0,0	7,6	9,2	8,I
	FE-II	9,2	I0,8	-	I0,7	I0,8	II,9	-	6,0	8,8	8,3
Cholesterol, mg/%	CC-II	I45	I67	I67	I45	I67	I50	I40; I36	2I5	-	200
	FE-II	I80	208	-	I82	220	I60	200; 2I0	280	235	250
Hemoglobin, g/%	CC-II	I2,2	I2,0	I2,4	I5,0	I3,5	I4,3	I3,6; I3,2	I4,2	I2,6	I4,I
	FE-II	II,8	I0,0	-	I2,8	II,2	I2,8	I2,5; I3,5	II,4	-	I3,0
Quantity of material taken	CC-II							I73,7; I42,2	223	I98,3	
	FE-II							I07,8; III,5	98	93,7	
Dry weight, %	CC-II							20,4; 2I,7	2I	20,5	
	FE-II							I8,2; I9,8	I9	I9,7	2I

[Commas in tabulated material are equivalent to decimal points]

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TABLE 2. RESULTS OF STUDYING BLOOD IN MC-I CREW MEMBERS BEFORE, DURING AND AFTER FLIGHT (DATA IN MG %)

Indices		Time period of the examination in days							
		Preflight III			In-flight		Postflight		
		-87	-68	-6	48	89	2	+ 8	+ I2
Urea,	CC -I	24	27	27	36	33	31,5	22	-
	FE -I	-	43	35	44	-	37,5	31,5	-
Nitrogen amino acid, mg%	CC -I	-	8,0	7,6	9,I	9,I	7,6	8,4	-
	FE I	-	7,5	5,3	-	-	9,2	7,6	-
Glucose	CC -I	75	68	80	57	54	85	80	81
	FE -I	-	85	95	-	-	II0	95	87
Inorganic phosphorus	CC -I	2,8	2,9	2,9	4,2	3,9	3,2	3,2	3,2
	FE -I	-	2,9	3,2	4,5	-	4,0	3,4	2,7
Acid soluble phosphorus	CC -I	-	-	20,0	21,0	I9,5	I8,5	I9,0	I8,5
	FE -I	-	-	I8,5	23,5	-	I7,5	I7,0	I6,0
Nucleotides	CC -I	50,7	42,0	44,5	42,5	44,5	40,0	39,0	39,0
	FE -I	-	45,5	34,5	-	-	-	32,0	36,0
Phosphorus 2,3 (calculated value)	CC -I	-	-	II,I	I2,0	II,I	I0,5	II,2	I0,7
	FE -I	-	-	II,6	-	-	-	I0,6	8,8
Lipid phosphorus	CC -I	II,2	I2,0	I0,5	9,0	9,5	9,0	8,5	-
	FE -I	-	I0,5	I2,5	I0,I	-	8,5	7,0	-
Chlosterol	CC -I	I55,0	I70	I80	I80	I85	I60	I85	-
	FE -I	-	I65	I85	I65	-	I65	I85	-
Hemoglobin	CC -I	I6,3	I4,0	I5,9	I6,7	I6,0	I6,4	I6,7	I5,7
	FE -I	-	I6,I	I5,0	II,4	-	I3,4	I3,8	I4,9

[Commas in tabulated material are equivalent to decimal points]

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latent and total iron bonding capability of the serum. The morphology and intracellular metabolism of leukocytes was studied by a method of light microscopy, statochemical determination of alkali phos- /229
phatase, myeloperoxidase, polysaccharides. Determination of the indices of kinetics of erythrocytes was done according to the method by Ye. N. Mosyagina.

As to the state of energy exchange in erythrocytes one judges according to the content of adenosine triphosphoric acid (ATP), the intensity of glycolysis, activity of lactate dehydrogenase (LDH), glucose-6-phosphate hydrogenase (G6PD), the content of restored glutathione (gsH). The intensity of glycolysis was evaluated according to the increase of uric acid in the erythrocyte cells incubated for 2 hours. The content of lactic acid and ATP were determined in perchloric extract by an enzyme spectrophotometric method. The activity of LDH was determined according to the Vu and Rakker method, G6PD--according to the Kornberg and Khrekker method. The content of restored glutathione was determined using 5'5 dithiobis-2-nitrobenzoic acid.

Results and their Discussion

Biochemical Composition of Blood and Mass of Hemoglobin

According to a number of research indices, biochemical analysis made in the 140-day flight showed shifts similar to those which took place during the 96-day flight (Tables 1, 2). Thus, on the 18th day in both crew members the content of urea increased (up to 43 mg% in the CC-II and 48 mg% in the FE-II) and continued to remain at a high level until completion of the flight. In the MC-I crew, the increase in content amounted to about 9 mg%. The increase in content of inorganic phosphorus was noted on the 75th day of flight in the members of the MC-II; however, by the 123rd day the concentration of it decreased and remained at this level after completion of the flight. Then, in the members of the MC-I crew, the content of inorganic phosphorus during flight was increased by 45% in comparison with the initial values. The changes of nitrogen amine in both cases were insignificant. At the same time, the data presented in Tables 1 and 2 are evidence of the fact that changes of a number of the indices /232
studied in the MC-II crew members were different from changes observed in the MC-I. Thus, in conditions on the 96th day of flight one did not detect shifts in the content of cholesterol and lipid phosphorus. At the same time, in members of the MC-II, the level of cholesterol on the 75th day was significantly increased; the values of lipid phosphorus at this time were, on the other hand, decreased. The increase in content of cholesterol with simultaneous decrease in lipid phosphorus can be reevaluated as a sign of activation of the atherosclerotic process. The content of acid soluble phosphorus was decreased in the MC-II crew whereas as in the CC-I and CC-II it remained without changes. Inasmuch as the concentration nucleotides changes insignificantly, the decrease in acid soluble phosphorus, probably, occurred due to a decrease in the content of 2,3-diphosphoglyceric acid (2,3-DPG) which can be evidence of a disturbance of

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TABLE 3. CHANGE IN THE MASS OF HEMOGLOBIN IN MC-I AND MC-II CREW MEMBERS

Expedition	Time period of observation	Total mass of hemoglobin (TMG)					
		TMG in g	Loss of TMG in g	Loss of TMG in %	TMG in g	Loss of TMG in g	Loss of TMG in %
			CC-I			FE-I	
MC -I	Preflight	678	-	-	767	-	-
	Postflight Day 1	5I8	I60	23,6	564	203	26,5
	Day 32	654	24	3,5	746	2I	2,7
			CC-II			FE-II	
MC-II	Preflight	735	-	-	760	-	-
	Postflight Day 3	62I	II4	I5,5	64I	II9	I5,7
	Day 7	-	-	-	633	I27	I6,7

[Commas in tabulated material are equivalent to decimal points]

TABLE 4. CHANGE IN THE VOLUME OF EXTRACELLULAR FLUID (VEF) IN MC-I AND MC-II CREW MEMBERS

Expedition	Time period of observations	VEF in 1	VEF in % of body weight	Loss of VEF in 1	VEF in 1	VEF in % of body weight	Loss of VEF in 1
MC-I			CC-I			FE-I	
	Preflight	I7,2	24,2	-	2I,6	28,0	-
	Day 1 after completion	I7,0	24,0	0,2	20,6	26,5	I,0
MC-II			CC-II			FE-II	
	Preflight	2I,2	25,I	-	22,0	29,0	-
	Day 1 after completion	I8,I	22,0	3,I	20,2	28,4	I8

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the transport oxygen.

The value of the dry residue of blood and concentration of hemoglobin for the extent of the entire 140-day flight in both cosmonauts varies insignificantly; this agrees with data obtained in the 96-day flight.

Studies of the acid soluble phosphorus and the 2,3-DPG entering into its composition is of interest from the point of view of verifying mechanisms which are the basis for disorders in the rate of synthesis of hemoglobin. The results of the studies of a mass of hemoglobin presented in Table 3 give evidence of a decrease in both crew members of the MC-II crew, on the average by 15%, in comparison with the initial data. On day 7 postflight in the FE-II, the mass of hemoglobin was even more decreased and amounted to 83.3% of the background indices. However, this decrease was smaller than that which was observed after 30-day, 49-day and 96-day flights.

Data on the dynamics of extracellular fluid are presented in Table 4. After the 140-day flight one noted a decrease in the volume of extracellular fluid more pronounced in the CC-II (3.1 ℓ or 14.6% of the initial value). In the FE-II, the decrease amounted to a total of 1.8ℓ or 8.2%. The decrease in volume of extracellular fluid gives evidence of the development of extracellular dehydration postflight. At the same time, after the 96-day flight, a decrease in volume of extracellular fluid was more pronounced. Thus, when studying the blood during and after a 140-day flight, the following changes were apparent: an increase in content of urea, decrease in mass of hemoglobin, the manifestation of extracellular dehydration, increase in content of cholesterol, decrease in lipid and acid soluble phosphorus. The changes noted in a number of indices of the biochemical composition of the blood were not observed in shorter flights; at the same time, they reached values making it possible to endanger the state of health of the cosmonauts. /235

Study of the State of the Blood System

Electron microscope study of the form and ultrastructure of erythrocytes showed that 89.5% of the cells in the CC-II and 86.5% of the cells in the FE-II are diskocytes of concavo-concave shape (Table 5, Figures 1, 2). Also a certain increase was noted in the cupola-shaped erythrocytes and erythrocytes shaped like a deflated ball (Table 5). During light microscopy, in the preparations one noted single erythrocytes with tooth and target-shaped forms. A study of the character of distribution of erythrocytes showed a decrease in the average volume by 6.6% in the CC-II and by 4.1% in the FE-II (Figure 3). During comparison with preflight values an increase was noted in the quantity of erythrocytes of the small value of mass (Table 6). Determination of the electrophoretic mobility of erythrocytes did not show significant changes (Figure 4). With prepared electrophoretic distribution, one observed a relative increase in fractions of erythrocytes with a large value of electrical

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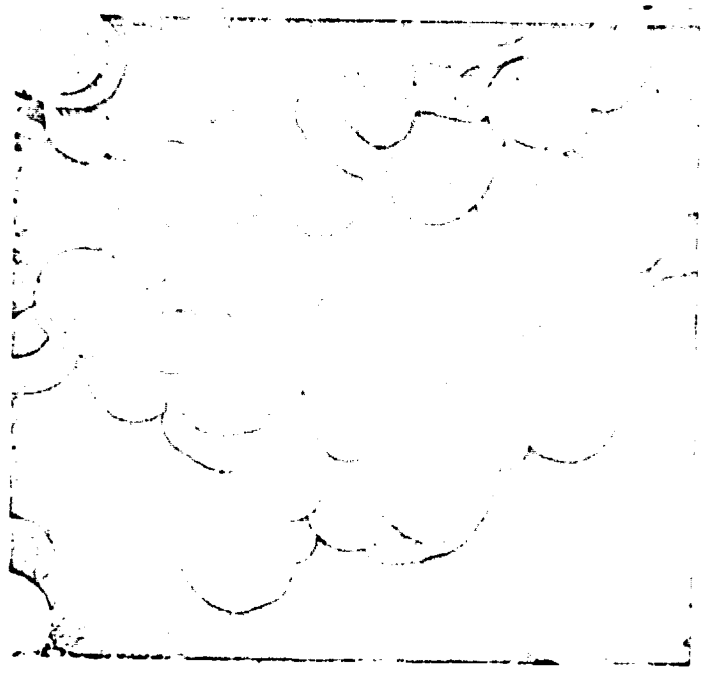

Figure 1. Electron microscope picture of the shapes of erythrocytes in the CC-II (day 1, X19,200)

charge. The position of the fractions with maximum content of cells corresponded to the normal.

The study of the structure of the hemoglobin showed that the composition [Page 241 missing but appears to be an error in pagination] of hemoglobin and the value of isoelectric points were unchanged /242 whereas fractions were discovered with more acid value of the iso-electric points characteristic for hemoglobin in mature forms of erythrocytes. When studying the functional parameters of curves of oxygenation of hemoglobin no significant changes were detected (value P_{50} and Hill coefficient--within normal limits). The indices of exchange of iron (concentration of iron in the serum, total and latent iron bonding capability of the serum) also were found within normal limits.

When studying the morphology of cells of the white series, there were no pathological changes detected. One noted the presence of a loose structure of lymphocyte nuclei and single thrombocytes of gigantic shape. The cytochemical study of intracellular metabolism leukocytes showed an increase in lymphocytes containing glycogen, the remaining parameters of exchange were found within limits of the norm. The studies made showed that on days 0 and 1 postflight, no changes were detected giving evidence of development of pathology in

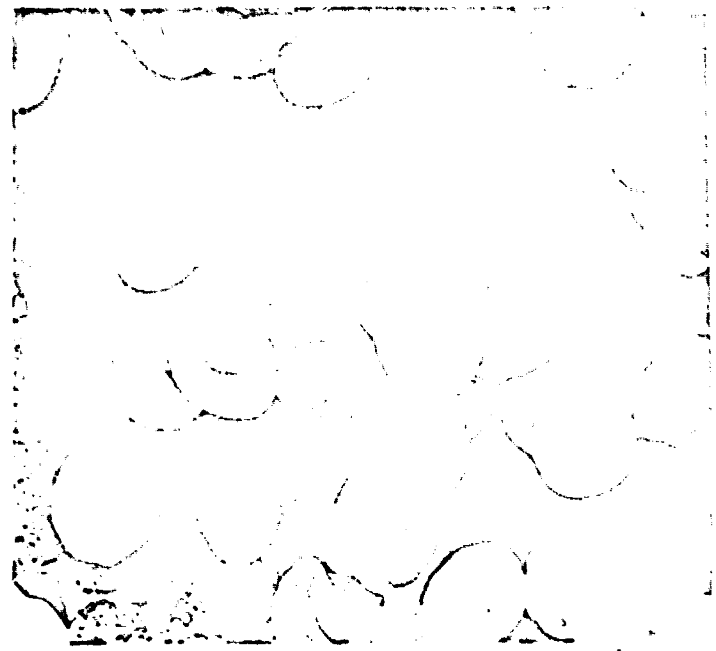

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Figure 2. Electron-microscope picture of the shape of erythrocytes in the FE-II (day +1, X18,000)

the blood system.

Determination of the Kinetics of Erythrocytes

The kinetics of erythrocytes in both cosmonauts after the 140-day flight changed unidirectionally. This was apparent on the first days postflight by a decrease in bone marrow production of erythrocytes with their quantity unchanged and a suppression of the proliferative activity of erythroid cells (decrease in the number of reticulocytes, Table 7, 8). By the 27th day after landing, in both crew members, one noted a decrease in the quantity of erythrocytes, an increase in the quantity of reticulocytes by 4 times and an increase in bone marrow production which apparently, can be explained by restructuring of erythrokinetics in the readaptation period.

State of the Energy Exchange in Erythrocytes

Study of certain indices of energy exchange in erythrocytes showed a decrease of it in both MC-II crew members on the first days after landing (Tables 9, 10).

TABLE 5. DISTRIBUTION OF ERYTHROCYTES ACCORDING TO SHAPE IN MC-II CREW MEMBERS

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Shape of the erythrocyte	% of total number of erythrocytes			
	CC-II		FE-II	
	Preflight	+ 1 day	Preflight	+ 1 day
Diskocytes	93,0	89,5	87,0	86,5
Diskocytes with single growth	I,5	I,0	2,5	2,5
Diskocytes with ridge	I,0	2,0	3,0	3,5
Diskocytes with multiple projections	I,0	0	3,5	0,5
Cupola-shaped erythrocytes	2,5	4,5	2,0	3,0
Erythrocytes shaped like mulberries	0	0	0	0
Erythrocytes shaped like a deflated ball	0,5	2,0	I,5	2,5
Spherical erythrocytes	0	0,5	0	0,5
Degenerative-changed erythrocytes	0,5	0,5	0,5	I,0

[Commas in tabulated material are equivalent to decimal points]

TABLE 6. PERCENTAGE DISTRIBUTION OF ERYTHROCYTES DEPENDING ON THE VALUE OF DRY MASS IN THE MC-II CREW MEMBERS

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Subjects	Value of the dry mass			
	20-29	30-39	40-49	
	Percent	Distribution	Erythrocytes	
Control group	I6,± 2,5	6I ± 3,0	22 ± 2,6	I,0 ± 0,[illegible]
" "	4,0-26	47-75	I0-33	0-7
CC-II				
Preflight	4	54	38	4
Day 0	I8	58	24	0
FE-II				
Preflight	4	68	24	[illegible]
Day 0	26	54	20	0
+I day	32	50	I8	0

[Commas in tabulated material are equivalent to decimal points]

Thus, the content of ATP decreased by 24.7% in the CC-II and by 43.1% in the FE-II; the intensity of glycolysis was decreased by 37.8% and by 42.3% in the CC-II and FE-II, respectively. In parallel with this, an insignificant decrease in activity of LDH was observed. The content of recovered glutathione in both cosmonauts decreased by almost two times. Also a decrease in activity of G6PD was noted (by 35.2% in the CC-II and by 41.2% in the FE-II), which attests to the change in intensity of the process of decomposition of glucose along the pentose-phosphate path. The data obtained differ from the results of studies made on the MC-I crew (Table 11). For instance, on days 1 and 7 after landing of the 96-day flight, a decrease in the quantity of ATP was observed in both cosmonauts; here, the other indices were within the limits of the norm. However, one should note that in this case the comparison of the data obtained cannot be fully competent, because in the case of the 140-day flight a recalculation of the data obtained was done in grams of hemoglobin and in the case of the MC-I per 1 ml of erythrocytes. At the same time, a decrease in content of ATP noted in the erythrocytes of the MC-I crew members can be due /247 to increased consumption of energy necessary for maintaining the structural entirety of the cell. The increased decomposition of ATP can be due to an increase in activity of NA^+ K^+-adenosine-triphosphatase. The examination made on the 35th day of the MC-I and on the 27th day of the MC-II showed that almost all of the indices studied are within the limits of the physiological norm.

The decrease we observed in indices of energy exchange in the red blood corpuscles in conditions of the 140-day flight possibly is due to the process of adaptation of the organism to weightlessness conditions.

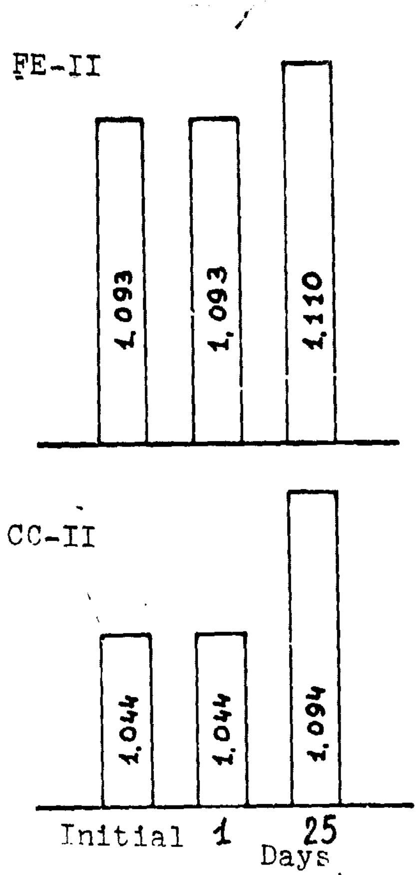

Figure 4. Electrophoretic mobility of erythrocytes in the MC-II crew. (Along the ordinate axis-- EPM in $\mu m \cdot cm\ V^{-1} \cdot s^{-1}$)

4.4. Immunologic Studies /249

Method

Blood for the studies was taken from the cubital vein on day 23 preflight and then on days 1 and 24 postflight. The material part of the study was also capillary blood which was taken from the finger on day 7 preflight and then on days 0, 1, 3 and 8 after landing. A fraction of lymphocytes and monocytes was separated for subpopulation analysis of immunocompetent cells from heparinized blood by a method of fractionation on phycol- [43].

The total content of thymus-dependent or T-lymphocytes was shown by a method of spontaneous E-rosette formation with sheep erythrocytes [44]. The content of "active" T-lymphocytes was determined using the "active" rosette test [45]. The content of B-lymphocytes with surface immunoglobulin receptors was determined by a method of immunofluorescent coloration [46]. For determining the content of B-lymphocytes with receptors to the complement, an EAC-rosette formation method was used [47].

Determination of lymphocytes with receptors to the Is-fragment

TABLE 7. INDICES OF KINETICS OF ERYTHROCYTES IN THE CC-II /243

Time period of the study	Number of erythrocytes mln/mn	Bone marrow production of erythrocytes (thousands per mm/day)	Number of reticulocytes (%)
Preflight	4,69	99,0	6,5
Postflight:			
Day 1	4,60	59,5	4,3
Day 27	4,40	248,0	17,[illegible]
Norm	4,52 - 4,88	69,6 - I92,6	[illegible]

[Commas in the tabulated material are equivalent to decimal points]

of immunoglobulins was done by a method described by Basten and co-authors [43]. Reactivity the thymus-dependent lymphocytes (or T-cells) was evaluated using a method of PHA-blast-transformation in the I.V. Konstantinova and Ye. N. Antropova modification during which radioaudiographically one determined the appearance in a 24-hour PHA-culture of lymphocytes with high heat synthesis, the RNA (including N^3-uridine) and in the 48-hour PHA-culture, the content of cells including N^3-thymidine. /249

The quantitative content of immunoglobulins of the four main classes, IqG, IqM, IqA and IqD was determined by a method of radioimmuno-diffusion in a gel (49].

The allergic examination included the following test. Specific blastoid transformation of lymphocytes of peripheral blood during /250 cultivation in the presence of allergens of the basic representatives of automicroflora of man was done according to the method described in [50]. The reaction of retardation of migration of lymphocytes was established using the A.G. Artem'eva micrometnod in a modification by L.A. Pol'ner and T.I. Serova This method was used both for determining the bacterial allergies and for diagnosis of allergies to chemical compounds characteristic for inhabited hermovolumes. Also, for this purpose the reaction of specific agglomeration of leukocytes was used according to O.A. Alekseyeva and L.A. Lueva.

TABLE 8. INDICES OF KINETICS OF ERYTHROCYTTES IN THE FE-II

Time period of the study	Number of erythrocytes mln/mm	Bone marrow production of erythrocytes (thousand in mm/day)	Number of reticulocytes (%) /244
Preflight	4,57	IOI,0	5,5
Postflight:			
Day 1	4,5I	47,6	3,2
Day 27	3,82	209,0	I3,5
Norm	4,52 - 4,88	68,8 - I92,6	8,5I-I4,5

[Commas in the tabulated material are equivalent to decimal points]

Intracutaneous clinical tests were made according to the usual method with an evaluation of the results after 48 hours. /250

Autoimmune tests included determinat on of autoantibodies of the IqM class opposite immunoglobulins of humans in the blood serum (reaction of agglutination to the latex-test reagent containing gamma globulin absorbed on the surface of particles in humans), and also by a method of determining antibodies opposite DNA.

Results of Studies and Their Discussion

After completing a 140-day orbital space flight the following information was found.

The quantity of thymus-dependent lymphocytes in both crew members of the main crew appeared sharply decreased in the early time periods of the examination. In the first days after landing, the content of T-lymphocytes determined by a method of rosette formation with erythrocytes of sheep, was 30% in the commander and 32% in the flight engineer (with the lowest boundary of the norm for this index 55%). On the 3rd day one noted similar figures, respectively, 45% and 40%. Only on day 7 was this index normalized. The normal level of T-lymphocytes is also found on day 24 after completion of the flight (Table 1).

TABLE 9. ENERGY EXCHANGE IN BLOOD ERYTHROCYTES IN THE CC-II

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Indices studied	Day +1	Day +25	Physiological norm
ATP in µM/g	4,242	7,097	5,636 ± 0,297
Intensity of glycolysis (according to increase in lactic acid in µM/g)	4,530	6,647	7,286 ± 0,265
Glutathione recovered in µM/g	4,444	9,200	9,818 ± 0,481
LDH in µMNADN$_2$/g in 1 min.	21,556	29,485	24,855 ± 0,461
G6PD in µM NADPN$_2$/g in 1 min.	2,833	2,775	4,374 ± 0,39[illegible]

[Commas in tabulated material are equivalent to decimal points]

The content of "active" T-lymphocytes in the first days was /250
significantly increased both in the commander in the flight engineer /253
(71% and 68%, respectively). Later on, in the commander and gradual normalization of the content of "active" T-lymphocytes was noted reaching on days 3 and 9 the upper boundaries of the norm (53% and 51%). On day 24, this index reached the preflight level. In the flight engineer, after a brief normalization apparent on day 3, in the succeeding examination period, on day 9, one noted a repeated increase in the content of "active" T-lymphocytes (57%) with a return to normal during analysis made a month after the flight. A study c the functional state of T-lymphocytes showed a sharp decrease : the activity of this most important population of immunocompentent cells (Table 2).

TABLE 10. ENERGY [illegible] EXCHANGE IN BLOOD ERYTHROCYTES IN THE FE-II

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Indices studied	Day +1	Day +25	Physiological norm
ATP in μM/g	3,206	5,897	5,636 ± 0,297
Intensity of glycolysis (according to increase of lactic acid in μM/g)	4,20I	5,663	7,286 ± 0,265
Glutathione recovered in μM/g	4,476	6,095	9,8I8 ± 0,484
LDH in μM $NADN_2$/g for 1 min.	I6,0I2	20,5I6	24,855 ± 0,46I
G6 PD in μM $NADPN_2$/g for 1 min.	2,573	4,II4	4,374 ± 0,393

[Commas in tabulated material are equivalent to decimal points]

The capability of the T-lymphocytes for blastoid transformation evaluated according to the discovery in the earlier time periods of cultivation of high labelled lymphocytes (containing 50 and more granules of recovered silver) was studied in the first 24 days. Preflight the PHA-reactivity of T-cells in both cosmonauts is normal (22.3% and 21.3% of high labelled according to N^3-uridine of cells). In the first days after landing, this index in the commander and flight engineer was sharply decreased (respectively, 3.3% and 2.7% with allowable normal variations from 15 to 26%). The capability of lymphocytes for proliferation in this time period in the flight engineer also was insignificantly decreased (12.7% lymphoctes including N^3-thymidine after 48 hours of cultivation of cells with PHA). On day 24 postflight, indices which characterize the functional state of the T-lymphocytes were fully normalized. /253

The study of the content of immunoglobulins in the blood (Table 3), showed in the early time periods postflight ("0" days and the first days after landing) a significant decrease in the flight engineer of the level of IqG (respectively, 590 mg% and 580 mg%).

TABLE 11. ENERGY EXCHANGE IN ERYTHROCYTES OF THE BLOOD IN MC-I CREW MEMBERS BEFORE AND AFTER FLIGHT

Indices studied	CC-I				FE-I				Physiological norm*
	Preflight	Day +1	Day +7	Day +30	Preflight	Day +1	Day +7	Day +30	
ATP in μM/ml er.	0,6I8	0,229	0,454	0,988	0,85I	0,356	0,488	I,066	0,823 ± 0,034
Intensity of glycolysis (according to increase of lactic acid in μM/ml of erythrocytes)	2,600	3,940	2,6I4	2,503	2,040	3,5I0	3,89I	2,450	4,208 ± 0,209
LDH in μM/NADN$_2$/ml of erythrocytes/min	4,667	3,995	4,II6	5,305	3,20I	3,927	4,030	5,583	4,240 ± 0,I85
G6PD in μMNADPN$_2$/ml of erythrocytes/min	I,060	I,440	I,032	I,093	0,943	I,336	I,398	I,3I8	0,89I ± 0,059

*Averaged data from 16 persons
x)

[Commas in tabulated material are equivalent to decimal points]

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TABLE 1. RESULTS OF SUBPOPULATION ANALYSIS OF LYMPHOCYTES OF THE PERIPHERAL BLOOD OF MEMBERS OF THE SECOND CREW OF THE SCIENTIFIC ORBITAL SALYUT-6 AND SOYUZ COMPLEX

Studies	Day of the study	Population of lymphocytes (%)				
		T(total)	T "active"	B (with immunologic receptors)	B (with receptors of the complement	With receptors
Spacecraft commander	Preflight					
	- 26	75.2	37.0	24.0	20.0	I7.0
	- 3	67.0	30.0	22.0	I8.0	I5.0
	Postflight					
	I	30.0	7I.0	I9.0	20.5	I6.0
	3	45.0	53.0		2I.0	I8.0
	9	67.0	5I.0		I2.0	[illegible]
	24	56.0	35.0	24.0	I5.0	I3.0
Flight engineer	Preflight					
	- 26	59.0	39.0	22.5	24.0	23.0
	- 7	63.0	2I.0	2I.5	I2.0	I3.0
	Postflight					
	I	32.0	68.0	I9.5	I9.0	II.0
	3	40.0	45.0		[illegible]	I5.0
	9	62.0	57.0		I3.0	20.0
	24	53.0	4I.0	26.0	I7.0	I9.0

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TABLE 2. REACTIVITY OF LYMPHOCYTES OF BLOOD IN REACTION OF PHA* BLAST-TRANSFORMATION, DEFINED BY INCLUDING RADIOACTIVELY LABELLED PRECURSORS OF NUCLEIC ACIDS (RADIOAUDOGRAPHY METHOD)

Test	Days of the study	Content of labelled cells (%)	
		Commander	Flight engineer
Lymphocytes with a high rate of synthesis of RNA (greater than 50 granules over cells, uridine-N^3) in a 24-hr culture with PHA	Preflight		
	- 26	21.3	22.3
	Postflight		
	I	3.3	2.7
	24	31.6	19.3
Content (%) of labelled lymphocytes according to thymidine-N^3 in a 48-hr culture with PHA	Preflight		
	- 26	40.0	40.2
	Postflight		
	I	22.0	12.7
	24	39.4	28.0

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*PHA--phytohemoglutinin (DifecP)
*)

In the commander, only on the day of landing, was a tendency noted toward a decrease in the level of IqC (910 mg% with preflight level 1310 mg%). The content of class A immunoglobulins in the flight engineer on "0" days and on the first days was significantly lower than the preflight (105 and 90 mg%, preflight content--460 mg%), remaining, however at a level close to the lower boundary of the norm. /253 /255

Determination of certain indices which characterize the presence of autoimmune reactions showed the following.

In the flight engineer preflight with multiple examinations one noted the presence in the blood of autoantibodies against human gamma globulin (positive reaction) on the landing day, in this cosmonaut, the reaction primarily remained positive. After 8 days, this reaction became even more pronounced (+++).

Both these cosmonauts underwent an allergologic examination (Table 4).

TABLE 3. THE CONTENT OF IMMUNOGLOBULINS, ANTIBODIES TO IMMUNOGLOBULINS IN MAN AND ANTIBODIES TO DNA IN THE BLOOD SERUM OF MEMBERS OF THE SECOND OF THE SCIENTIFIC ORBITAL SALYUT-6 AND SOYUZ COMPLEX

Studied	Day of study	Content of immunoglobulins (mg%)				Antibodies against DNA (titer)	Antibodies against human immunoglobulins (latex test)
		IgC	IgA	IgM	IgD		
Commander	-23	I4[illegible]0	420	92	0	8	-
	-6	I3I0	385	I24	[illegible]	Not determined	-
	Postflight						
	0	[illegible]0I0	235	64	8	I3	-
	I	I0I0	255	88	0	I4	-
	24	I220	252	I34	I	34	-
Flight Engineer	Preflight						
	-23	I030	365	74	I	2	+
	-7	I030	430	64	[illegible]	Not determined	+
	Postflight						
	0	5[illegible]0	I05	30	2	3	+
	I	[illegible]30	[illegible]00	70	2	I3	
	3	[illegible]30	235	74	0		+++
	24	I0I0	320	74	0	I3	+++

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In the postflight period, in the flight engineer the appearance of signs of hypersensitivity of a retarded type absent earlier toward microallergens was established (staphylococcus and streptococcus). This was confirmed by the behavior of the appropriate positive skin tests and for streptococcus--also by production *in vitro* of lymphocytes of the corresponding lymphokines (factor of inhibition of migration of leukocytes). /255

TABLE 4. ALLERGOLOGIC EXAMINATION OF CREW MEMBERS OF THE SCIENTIFIC RESEARCH SALYUT-6 AND SOYUZ COMPLEX (SECOND EXPEDITION) /256

Test	Commander Pre-flight	Commander Post-flight	Flight engineer Pre-flight	Flight engineer Post-flight
I. Specific blast-transformation *in vitro* (% of transform cells)				
to staphylococcus	1.5	2.5	-	-
to streptococcus	1.8	2.0	-	-
2. Determination of the factor of inhibition of migration of leukocytes (MIF)				
to staphylococcus	++	+	-	-
to streptococcus	++	+	-	+
to formaldehyde	not det.	++	not det.	-
3. Clinical intracutaneous test (hypersensitivity of the retarded type)				
to staphylococcus	-	+	-	+
to streptococcus	++	++	-	+
4. Reaction of agglomeration of leukocytes to chemical allergens				
furfural	not det.	-	not det.	-
phthalic anhydride	not det.	-	not det.	-
diotilglycol	not det.	-	not det.	-
triethylglycol	not det.	-	not det.	not det.
formaldehyde	not det.	+	not det.	+

After the flight a test was made of the possible appearance of hypersensitivty to a certain substance of chemical nature. Compounds were selected which are widespread industrial allergens and concentrations were determined differently in hermetically sealed inhabited volumes. In the blood samples taken on days 1 and 24 post landing, a positive reaction was discovered to formaldehyde. The index of agglomeration of leukocytes on these dates was equal to 2.0 and 1.8 in the commander and 1.5 and 1.6 in the flight engineer. The reaction of inhibition of migration of leukocytes also was apparent in the commander with a noticeably pronounced positive reaction to formaldehyde (++). /255

In this way, in the crew of the second expedition of the scientific Salyut-6 and Soyuz complex, after the 140-day stay in flight conditions, changes in immunologic reactivity were apparent. /257

The dynamics of many of these changes apparent during blood analysis taken from the finger were traced in adequate detail.

Changes in the content of separate populations of immunocompentent lymphocytes were very pronounced although short-lived and also hypogammoglobulinemia of the IqG-type, very deep in the flight engineer and insignificant in the commander. In the flight engineer in the first 2 days, one noted a relative hypogammoglobulinemia of the IqA-type.

The reactivity of thymus-dependent lymphocytes requiring venous blood was determined after landing, twice, on days 1 and 24 after landing. In the first days, in both cosmonauts a severe drop in functional activity of T-lymphocytes was discovered. After 24 days, this index corresponded to the preflight level.

Apparently, conditions of staying onboard an orbital station affect primarily T-lymphocytes. The content of B-cells, both as a total determined by an immunofluorescent method and in the subpopulation apparent in the presence of receptors to the complement, did not change after the 140-day flight.

Damage to the T-lymphocytes themselves is also comfirmed by symptoms of sensitization of the organism to a number of allergens. The manifestation in one of the cosmonauts for hypersensitivity of a retarded type to bacterial allergens (staphylococcus and streptococcus) was discovered. Tests with chemical allergens preflight were not made and therefore a discussion in both cosmonauts after landing as to pronounced sensitization of formaldehyde requires a certain amount of care. In spite of the fact that one does not encounter a standard for sensitization to this chemical substance, it is impossible to completely exclude the possibility of the appearance of high sensitivity to formaldehyde earlier, for example, in the stages of preparation for flight. A detailed analysis of /258
sensitivity to the chemical allergens before and after space flights will be continued in the future. However, even right now, the data obtained on the presence of sensitization in the cosmonauts to this component, constantly defined in small quantities in different types of hermovolumes, can be used as the basis for conducting a number of appropriate practical measures directed at analysis of the sources for generation into an artificial atmosphere of formaldehyde or its compounds and a search for eliminating them.

Thus, after landing the 140-day flight, changes were noted in immunoreactivity which are distinguished by significant appearance and polymorphism.

Up to the present time, the question remains open of the connection of the increasing duration of man's stay in space flight conditions with an increased disturbance in the system of immunologic protection of the organism.

On the one hand, in spite of a high frequency of individual peculiarities of immunoreactivity, and also the small number of observations for separate flights of considerable duration, there are certain bases for assuming definite stages of adaptation of the immunocompetent system to the effect of space flight factors. After 30-day and 63-day orbital flights we discovered a number of marked changes some of which had not disappeared a month after landing.

After increasing the duration of flight to 96 days, we discovered hardly any rough changes in immunoreactivity postflight. Then after the 140-day flight, again in both cosmonauts a number of significant deviations occurred relating both to the quantitative characteristics and the functional tests which characterize the state of separate mechanisms of immunologic reactivity.

On the basis of the observations made one can propose that the first stage of adaptation of the immunocompetent system in conditions of space flight occurs during the first 2 to 3 months after which a subsequent stage sets in marked by a secondary imbalance of the mechanisms defined. Finally, a further accumulation of factual material improvement from flight to flight of the system of prophylactic measures used on board and a number of other moments can result in serious corrections in our concepts of dynamics of adaptive reactions of the immunity system which occur in flights of long duration. /259

A study is considered necessary of immunologic reactivity, directly in flight for isolating the initial deviations, which occur in these conditions, from possible reactions of readaptation to Earth conditions.

What has been presented applies to a basic circle of problems involving prediction of change in the reaction of the immunities, providing resistance of the organism to bacterial and virus infection and resistance to autoaggression. Moreover, apparently, special attention of specialists must be directed at a problem involving danger of complication of an allergic nature occurring in conditions of long-term space flight.

4.5. Microbiological Studies /260

Method

In the process of preparation and accomplishment of flight of the second main crew, a study was made of the visible composition and quantitative indices of microflora of the nasal cavity, the oral cavity, and the skin of cosmonauts and also the quantitative and qualitative composition of their intestinal microflora.

In the preflight and postflight period, selection of samples of microflora was accomplished by the classical method and in the flight process using a specially developed apparatus which provides preserving the microflora for the time period necessary for delivery of the samples to Earth.

Inoculation of the microflora was done on a number of selective and differential diagnostic media. Identification of the micro-organism was made in accordance with joint Soviet-American administration [51].

A study of quantitative relationships in microbiocenosis of the intestine was done according to a method recommended by Haenel and Muller--Benthow [52] in the N.N. Liz'ko modification [53, 54]. The following groups of microorganisms were considered quantitatively: the total quantity of anaerobic bacteria, bacteroids, biphydobacteria, the total quantity of aerobic bacteria, lactobacilli, intestinal bacilli, streptococci, enterococci, clostridia, staphylococci, yeasts, the total quantity of conventionally pathogenic enterobacteria, protei. Determination of the total quantity of anaerobic bacteria, bacteroids, byphydobacteria and lactobacilli was done using the application of indicators with 4--5 hour cultures of Serratia marcescens in the dish with the appropriate nutrititive media for creating /261 anaerobic conditions. Isolation and proven quantitative calculation of the conventionally pathogenic microflora of the family Enterobacteriaceae was accomplished using a Bendig, Haenel method [55] in a modification by S.K. Kanareykina and N.N. Liz'ko [56].

The strains isolated were identified using a number of biochemical tests recommended by G.P. Kalina [57].

Results of the Studies and their Discussion

The studies made when carrying out flights of the Soyuz spacecraft series and the Salyut orbital stations showed [58, 59, 60] that in conditions of man's living in space object cabins, the following changes occur in the composition of automicroflora of their integuments in most cases:

-- the total number of representatives of normal microflora changes;

-- on the mucous membranes of the upper respiratory tracts microorganism appear which are not inherent for vegetation on these sections of man's integuments;

-- in carriers of pathogenic microflora the number of microfoci increases formed due to these microorganisms;

-- a temporary colonization of pathogenic staphylococci occurs on mucous membranes of the upper respiratory tracts in persons free from these carriers earlier, as a result of transmission of the indicated microorganisms from other crew members;

-- biological properties of pathogenic representatives of microflora change toward an increase in their pathogeneity.

In accordance with the existing representatives [61, 62] the recorded changes are considered as disbacterial and are one of the predisposition states in development of infectious diseases.

There is a basis for considering that the indicated diseases can develop not only as a type of autoinfection but also as a result of interexchange of representatives of microflora in the form of so-called "intersecting infection." This circumstance was the basis for conducting studies on the microflora of the air atmosphere and internal surfaces of the orbital Salyut station as the basic factors for transfer of microorganisms in these conditions. /262

Such studies were made during operation of the crews in the orbital Salyut-1, Salyut-4 and Salyut-6 stations (first main crew).

The data obtained attest to the possibility of a significant accumulation of microorganisms in the air atmosphere and on the internal surfaces of the interior and equipment of the station. Then, in tests one detected pathogenic staphylococci and from certain surfaces microorganisms of the Proteus miralilis species were isolated in a large quantity; these were capable of causing diseases in man.

The first main crew worked in the orbital Salyut-6 station for a period of 96 days. Then, in the cosmonauts one noted marked changes in the species composition of the microflora of the upper respiratory tracts. The time periods for the second main crew in the station was increased to 140 days. However, when conducting studies of the microflora of these cosmonauts during flight, no unfavorable changes were established (see Tables 1--4). The microflora of the mucous membranes of the upper respiratory tract and skin of the palms in crew members represented constant inhabitants of these section in healthy persons.

In the nasal cavity, primarily the following were determined: epidermal staphylococci, Corynebacteria (C. Pseudodiphteriticum C. equi, C. group C) in the nasal cavity and mounth--Streptococcus saliv., streptococci IV of the biochemical type, nonhemolytic streptococci, epidermal stephylococci, Corynebacteria (C. group G), on the skin of the hands basically--epidermal staphylococci. No pathogenic staphylococci or other microorganism which are considered as possible agents for infectious diseases in the cosmonauts were discovered during flight. /271

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TABLE 1. MICROFLORA OF THE NASAL CAVITY OF COMRADE V.V. KOVALËNOK

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Indices studied	Sampling by classical method			Sampling using flight apparatus				Sampling by a classical method		
	Preflight days			Day of launch	Day 19 of flight	Day 138 of flight	Day of landing	Days postflight		
	24	4	0					0	4	7
Total quantity of microflora on the tampon (blood agar)	I,5xI0^3	3xI0^3	I,5xI0^5	3xI0^2	I,8xI0^5	2xI0^6	2,6xI0^4	8,6xI0^5	2xI0^5	2,7xI0^4
Quantity of staphylococci (blood agar)	I,5xI0^3	(?) not det.	2,8xI0^4	3xI0^2	4xI0^3	7xI0^4	9xI0^3	7 xI0^4	6xI0^4	I,5xI0^4
Quantity of nonhemolytic streptococci (blood agar)	[illegible]	2xI0^3	2xI0^3	not det.	not det.	not det.	I,6xI0^4	4 xI0^5	I,5xI0^5	[illegible] xI0^3
Quantity of β hemolytic streptococci (blood agar)	not det.	not det.	not det.	not det.	not det.	not det.	not det.	I,2xI0^5	not det.	not det.
Quantity of gram-positive bacilli of Corynebacterium of the G group (blood agar)	not det.	9xI0^2	I,2xI0^5	not det.	not det.	not det.	not det.	not det.	not det.	not det.
Quantity of gram-positive bacilli of Corynebacterium pseudodiphter. (Blood agar)	not det.	not det.	not det.	not det.	not det.	not det.	IxI0^3	4xI0^4	not det.	not det.

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TABLE 1. CONTINUED

	2	3	4	5	6	7	8	9	10	11
Quantity of gram-positive bacilli Corynebacterium group C	(K) not det.	not det.	not det.	not det.	$1{,}7 \times 10^{5}$	not det.	not det.	not det.	not det.	not det.
Quantity of pathogenic staphylococci of phagotype (mannitol-salt agar)	not det.	not det.	not det.	not det.	not det.	not det.	not det.	1×10^{1} 3c/55	3×10^{3} 3c/55/71	not det.
Quantity of Neisser species Neisserium flavescens (blood agar)	not det.	not det.	not det.	not det.	not det. ?	$1{,}9 \times 10^{5}$	not det.	not det.	not det.	264 rot det.
Quantity of gram-positive bacilli Corynebacterium equi (blood agar)	not det.	not det.	not det.	not det.	not det.	not det.	not det.	4×10^{4}	not det.	3×10^{3}

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TABLE 2. MICROFLORA OF THE NASAL CAVITY OF COMRADE A.S. IVANCHENKOV

Indices studied	Sampling by classical methods			Sampling using flight apparatus				Sampling by classical methods		
	Preflight, days			Day of launch	Day 19 of flight	Day 138 of flight	Landing day	Postflight days		
	28	4	0					0	4	7
Total quantity of microbes on the tampon (blood agar)	$3,3xI0^4$	$2,7xI0^5$	$4,7xI0^4$	$3,6xI0^2$	$3,6xI0^3$	$3,7xI0^4$	$5,IxI0^4$	$8,IxI0^5$	$2,IxI0^5$	$2,9xI0^4$
Quantity of staphylococcus (blood agar)	$9 x I0^3$	$2,7xI0^5$	$4,7xI0^4$	$3 xI0^2$	$3,6xI0^3$	$3,6xI0^4$	$I,2xI0^4$	$3,6xI0^5$	$I,8xI0^5$	$2,IxI0^4$
Quantity of nonhemolytic streptococcu (blood agar)	$IxI0^3$	Not det.	Not det.	Not det.	Not det.	$5xI0^2$	$3,9xI0^4$	$4,5xI0^5$	Not det.	Not det.
Quantity of corynebacteria Corynebacterium equi (blood agar)	$I,3xI0^4$	Not det.	Not det.	Not det.	Not det.	$5xI0^2$	Not det.	Not det.	Not det.	Not det.
Quantity of corynebacteria Corynevacterium pseudo-diphteriticum (blood agar)	Not det.	Not det.	Not det.	$6xI0^I$	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.

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TABLE 2. CONTINUED

I	2	3	4	5	6	7	8	9	I0	II
Quantity of pathogenic staphylococci, phagotype (mannitol-salt agar)	Not det.	$3x10^2$ H/[illegible]	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	$3,3x10^4$ 53/83a	Not det.
Quantity of corynebacteria Corynebacterium group G	$1x10^4$	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	$3,3x10^4$	$8x10^4$

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TABLE 3. CONTINUED

I	2	3	4	5*	6*	7*	8	9	IO	II
Quantity of staphylococci (blood agar)	I,2xIO^{7}	Not det.	2xIO^{5}	Not det.	I,8xIO^{4}	9xIO^{3}	I,8xIO^{5}	3xIO^{6}	I,9xIO^{7}	7xIO^{6}
Quantity of gram-positive bacilli Corynebacterium equi (blood agar)	Not det.	IxIO^{6}	3,8xIO^{6}	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.
Quantity of gram-positive bacilli Corynebacterium group G (blood agar)	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	I,5xIO^{5}	3 xIO^{6}	IxIO^{6}	Not det.
Quantity of pathogenic staphylococci, phagotype (mannitol-salt agar)	IOKO- I,9xIO^{3} 3a/8I and n/pc	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	2xIO^{2} H/π	Not det.

*Quantity of microbes per tampon

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TABLE 3. MICROFLORA IN THE ORAL CAVITY AND THROAT OF COMRADE V.V. KOVALЁNOK

Indices studied	Sampling by classical methods			Sampling using flight apparatus				Sampling by classical methods		
	Preflight day			Day of launch	Day 19 of flight	Day 138 of flight	Day of landing	Days postflight		
	28	4	0	*	*	*		0	4	7
Total number of microbes per 20 ml of wash (blood agar)	*I,4xI0^{7}	2xI0^{6}	6xI0^{7}	2,6xI0^{5}	2,4xI0^{4}	4,5xI0^{4}	3,3xI0^{5}	7,2xI0^{7}	I,2xI0^{8}	I,5xI0^{7}
Quantity of β-hemolytic streptococci (blood agar)	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	4,6xI0^{7}	2x I0^{7}	Not det.
Quantity of nonhemolytic streptococci (blood agar)	2 xI0^{6}	I xI0^{6}	He обн.	IxI0^{3}	6xI0^{3}	Not det.	Not det.	2xI0^{7}	4xI0^{7}	5xI0^{6}
Quantity of α-hem. streptococci Str. salivarius (blood agar)	Not det.	Not det.	5,6xI0^{7}	2,5xI0^{5}	Not det.	I,8xI0^{4}	Not det.	Not det.	2xI0^{7}	Not det.
Quantity of α-hem. streptococci type IV	Not det.	Not det.	Not det.	Not det.	Not det.	I,8xI0^{4}	Not det.	Not det.	2xI0^{7}	Not det.

*Quantity of microbes per tampon

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TABLE 4. MICROFLORA OF THE ORAL CAVITY AND THROAT OF COMRADE A.S. IVANCHENKOV

Indices studied	Sampling by classical methods			Sampling using flight apparatus				Sampling by classical methods		
	Days preflight			Day of launch	Day 19 of flight	Day 138 of flight	Landing day	Postflight days		
	28	4	0					0	4	7
Total quantity of microbes in 20 ml of wash (blood agar)	$6{,}8 \times 10^7$	$2{,}8 \times 10^7$	1×10^8	$6{,}6 \times 10^3$	$1{,}5 \times 10^3$	$4{,}8 \times 10^5$	$2{,}4 \times 10^5$	$1{,}2 \times 10^8$	$9{,}4 \times 10^8$	$1{,}2 \times 10^7$
Quantity of β-hemolytic streptococci (blood agar)	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	7×10^7	1×10^7	Not det.
Quantity of α-hem. streptococci Streptococcus salivarius (blood agar)	$2{,}6 \times 10^7$	1×10^6	7×10^7	$6{,}6 \times 10^3$	Not det.	2×10^5	Not det.	1×10^6	5×10^8	Not det.
Quantity of α-hem. streptococci Straptococcus mitis (blood agar)	Not det.	1×10^6	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.
Quantity of α-hem. streptococci type IV (blood agar)	Not det.	Not det.	6×10^6	Not det.	Not det.	Not det.	Not det.	9×10^6	1×10^8	Not det.

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TABLE 4. CONTINUED

I	2	3	4	* 5	* 6	* 7	8	9	IO	II
Quantity of nonhemolytic streptococci (blood agar)	I,8xIO^{7}	2,2xIO^{7}	3xIO^{6}	Not det.	Not det.	I,9xIO^{5}	IxIO^{4}	4xIO^{6}	2xIO^{6}	Not det.
Quantity of staphylococci (blood agar)	2,2xIO^{7}	(+) Not det.	I,3xIO^{7}	Not det.	I,6xIO^{3}	9xIO^{4}	2,3xIO^{5}	3,6xIO^{7}	7,8xIO^{7}	3xIO^{6}
Quantity of corynebacteria Corynebacterium pseudo-diphteriticum (blood agar)	Not det.	2xIO^{6}	I,5xIO^{6}	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.
Quantity of corynebacteria Corynebacterium equi (blood agar)	Not det.	Not det.	I,5xIO^{6}	Not det.	Not det.	Not det.	Not det.	Not det.	2,2xIO^{8}	Not det.
Quantity of corynebacteria group G (blood agar)	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	Not det.	9xIO^{6}
Quantity of pathogenic staphylococci of the phagotype (mannitol-salt agar)	Not det.	2xIO^{2} 3C/55/7I	Not det.	Not det.	Not det.	Not det.	Not det.	I,8xIO^{2} 53/83A	2xIO^{3} 3c/55/7I	IxIO^{3} 3c/55/7Ia/T

*[illegible]

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The peculiarity of composition of microflora of the nasal cavity of crew members in the last days of flight was the presence in the samples of nonhemolytic streptococci, and in comrade V.V. Kovalënok, besides this, nonpathogenic Neisseria, belonging to the Neisserium flavescens species.

In essence, the microflora of the upper respiratory tracts of cosmonauts during flight retained the characteristics inherent in them in the preflight period. Appropriate studies made during the month after launch showed that the automicroflora of the skin in members of the second main crew was characterized by quantitative and qualitative indices within the limits of values inherent in a healthy person. In this period, pathogenic staphylococci were detected in the upper respiratory tracts of cosmonauts only once. Part of the strains of staphylococci isolated from comrade V.V. Kovalënok belong to the phagotype ZA/81, and the other part--two microbes of an untyped international set of staphylococci bacteriophages. Staphylococci detected on day 4 prelaunch in comrade A.S. Ivanchenkov had phagotypes ZC/55/71 or were of the untyped form.

The absence of significant shifts in the composition of microflora of the skin in cosmonauts was confirmed also by the results of studies of therapeutic stability of staphylococcus flora. Studies made earlier showed that the appearance of disbacteriotic changes in the composition of microflora of the cosmonauts, as a rule, is accompanied by a change in biological properties of its separate representatives, in particular, the sensitivity of staphylococci grown on the integuments to antibiotics. When conducting these studies, no changes in this index was noted in the cosmonauts.

A certain epidemiologic danger for members of the main crew exists /272
with the visits carried out to the orbital Salyut-6 station. With the combined stay of two crews in the station rooms, the possibility of infection of cosmonauts with pathogenic microorganisms during interexchange of microflora increased considerably. The long term stay in isolation and the effect of space flight factors to which they were subjected was particularly important for members of the main crew.

Due to this, for conducting preflight examination of members of the visiting crew, particular attention was devoted to establishing barriers of pathogenic microflora among them and evaluating the epidemiologic danger.

Studies showed that in the upper respiratory tracts of the cosmonaut-scientists in first crew of the visitors in the preflight period, pathogenic staphylococci, untyped in the international set of staphylococci bacteriophages, and gram-negative bacilli of the Klebsiella edwardsiella type were detected.

Pathogenic staphylococci were isolated also from the oral cavity and throat of the commander of the second visiting crew. The indicated microorganisms belong to the 53/83A phagotype and had a high toxigenic activity. In the oral cavity of the cosmonauts scientists in this crew β-hemolytic streptococci were isolated in the prelaunch period.

The microorganisms listed are considered as possible agents of infectious disease in space flight conditions. The circumstance indicated was the basis for conducting special studies directed at determining the potential danger from the carriers discovered of conventionally pathogenic microorganisms for members of the main crew.

The data obtained are evidence of the fact that members of the visiting crews are not active generators of pathogenic staphylococci, β-hemolytic streptococci and klebsiella in the ambient atmosphere.

After completion of space flights, a manifestation was noted in members of the visiting crews of a significant quantity of pathogenic staphylococci, in a number of cases not detected in them in the immediate preflight period. Here, the total number of microbes increased insignificantly in the cosmonauts. An explanation of this phenomenon can include the fact that the visiting expeditions stay in the orbital Salyut-6 space station coincided with the period of their adaptation to the effect of space flight factors.

Apparently, in the process of this restructuring of the organism of cosmonauts, a tendency occurs for activation of conventional pathogenic microflora and conditions are created for their manifestation as a result of an increase in the existing microbe "latent" focus of carriers of pathogenic staphylococci which earlier was not successfully determined when conducting studies in the preflight period.

In the process of microbiologic study of members of the second main crew, significant changes in composition of their automicroflora were recorded in the immediate postflight period. They showed up (day of landing and day 4 postflight) in the upper respiratory tracts of cosmonauts as pathogenic staphylococci and β-hemolytic streptococci.

The content of β-hemolytic streptococci in the oral cavity of crew members of the second main crew in this period was extremely high 8--9 X 10^7 microbes for 20 ml of wash and in the cosmonaut V.V. Kovalënok the indicated microorganisms were discovered also in the nasal cavity where their quantity reached 9 X 10^4 microorganisms per tampon. Such a significant degree of increase of microbe inoculation in the upper respiratory tracts with β-hemolytic streptococci, /274
considering their role in infectious pathology in man, can be considered in accordance with bibliographical data [63, 64] as an unfavorable prognostic characteristic. After 7 days postflight the microflora of the upper respiratory tracts of cosmonauts normalized in its index. The results of phagotyping of pathogenic staphylococci isolated from the upper respiratory tract in the cosmonauts gives us the basis for hypothesizing that in the process of combined stay in the orbital station a transfer of pathogenic staphylococci of the 3C/55/71 phagotype was possible from cosmonaut A.S. Ivanchenkov to a second member of the crew. Colonization of the staphylococci of the 3C/55/71 phagotype on mucous membranes of the nasal cavity in comrade V.V. Kovalënok was temporary. On the 7th day, pathogenic staphylococci began to be isolated in him. In cosmonaut A.S. Ivanchenkov, on the day of landing, also pathogenic staphylococci of the 53/83A phagotype which are not characteristic for him were detected in the oral cavity. Staphycococci of this phagotype both pre and postflight were discovered

in the oral cavity of the commander of the second main crew, V.S. Bykovskiy. However, we have no direct data on the mechanism of transfer which is the basis for the noted interexchange by pathogenic staphylococci. In a later long term time period after landing, in the upper respiratory tracts of cosmonaut A.S. Ivanchenkov, again one began to detect pathogenic staphylococci characteristic for him belonging to the 3C/55/71 phagotype; this is evidence of recovery of the microbe picture inherent for him.

Microflora of the skin both in members of the main crew and in visiting crews during the periods of studies was represented by epidermal staphylococci and corynebacteria of different species: C. zerosis, C. pseudodiphtariticum, C. Bovis, C. equi, C. groups G and C according to Evans.

Pathogenic microorganismson the sections of skin studied in the cosmonauts were not determined. An increase in the total number of microbes on the skin of the cosmonauts postflight, in comparison with /275
the results of preflight studies, was not noted in most cases. Changes in the species composition of microflora in different time periods of examination resulted in a change in the ratio of staphylococci and corynebacteria and also a shift in the single dominating species of the other Corynebacteria. When comparing the data presented with the results of studies made earlier (flights of the Soyuz series spacecraft, first main expedition to the Salyut-6 station) a direct relationship between the expression of shifts in the state of automicroflora of the skin in cosmonauts and time period for work of members in Space was not successfully established. As was pointed out, the duration of space flight does not have a direct effect on the degree and character of microcontamination of the habitable medium of space objects. To a significant degree, the latter depends on the volume of sanitary measures taken and observation of routines for using them.

The sanitary and epidemiologic circumstances on board the orbital station with multi-month time periods for functioning, primarily, are determined by such factors as individual characteristics of the microbiological status inherent in the cosmonauts, expression of adaptation reactions to conditions of space flight, the character of work done, the thoroughness of fulfilling the measures described for maintaining a sanitary and hygienic routine, the volume and character of persional hygiene methods used.

As to prevention, apparently, the most important must be development of the complex of sanitation measures directed at normalizing the composition of microflora of cosmonauts for stages of preparation and in the process of completing spaceflights by them.

In accordance with the data obtained one can conclude that in the initial period of readaptation of cosmonauts,who have completed long-term space flights, to conditions of Earth, conditions are created which are favorable to development of infectious diseases in them. The circumstance indicated makes it necessary to develop and use /276
measures for prevention applicable to this period.

When studying the intestinal microflora in the first crew members of the second expedition 24 days preflight, insignificant disbiotic changes were apparent in biocenosis of the intestines applying only to a disturbance in the relationship between biphytobacteria and intestinal bacilli. As to the quantitative content of the remaining groups of microorganisms there were no peculiarities noted in the picture of Escherichia, enterococcus flora, or in the species composition of conventionally pathogenic enterobacteria. When identifying isolated cultures of bacteria of the Enterobacterioceae family, bacteria of the genuses Citrobueter (8×10^4) and Kl. pneumonae (2×10^4) were detected whose content did not exceed the norm established for healthy persons. Taking into account the lability shown earlier of intestinal microflora to the stress effects, and also duration before the flight for maintaining stability of microbe cenosis of the intestine and prophylaxis of disbacteriosis, the use of the drug Byphydumbacterin was recommended with 10 doses per day for 2 weeks. When studying the composition of the intestinal microflora for 24 hours preflight, hygiene showed a favorable effect which was marked by disappearance of conventionally pathogenic enterobacteria and a certain decrease in content of enterococci. In the prelaunch period, no changes were noted in the quantitative content of lactobacilli and a decrease in biphydobacteria was not marked (Figure 1, CC-II).

During studies on the 6th day postflight, no significant changes were detected in the state of the aerobic flora of the intestines. The content of intestinal bacilli, streptococci, conventionally pathogenic enterobacteria were found in limits of the norm established for healthy mature persons. During identification of representatives of the family Enterobacteriaceae bacteria of the Citrobacterec species was isolated (6×10^3). Besides an absence of significant shifts in the aerobic flora of the intestines, in the postflight period one detected a decrease in lactobacilli (by almost 100 times) and disappearance of biphydobacteria. /278

In subsequent time periods of the study, on days 10 and 25 of the postflight period, no peculiarities were discovered in microbe cenosis of the intestine in comparison with the preceding examination. On day 25 postflight a certain increase in the content of lactobacilli was noted.

In the second member of the crew on day 24 preflight a disturbance in the relationship between byphydobacteria and intestinal bacilli was discovered, the latter only insignificantly lower than the content of the first. In quantitative and species characteristics of the remaining groups of microorganisms determined, there were no peculiarities. For stabilization of biphydoflora and also taking into account its lability in extreme conditions, in the second cosmonaut, as in the first, intake of Biphydumbakterin was recommended in a quantity of 10 doses per day for 2 weeks.

When studying the composition of intestinal microflora for 4 days preflight no changes were discovered in the biphydoflora for lactoflora (Figure 1, FE-II).

On the second day postflight, in the composition of intestinal

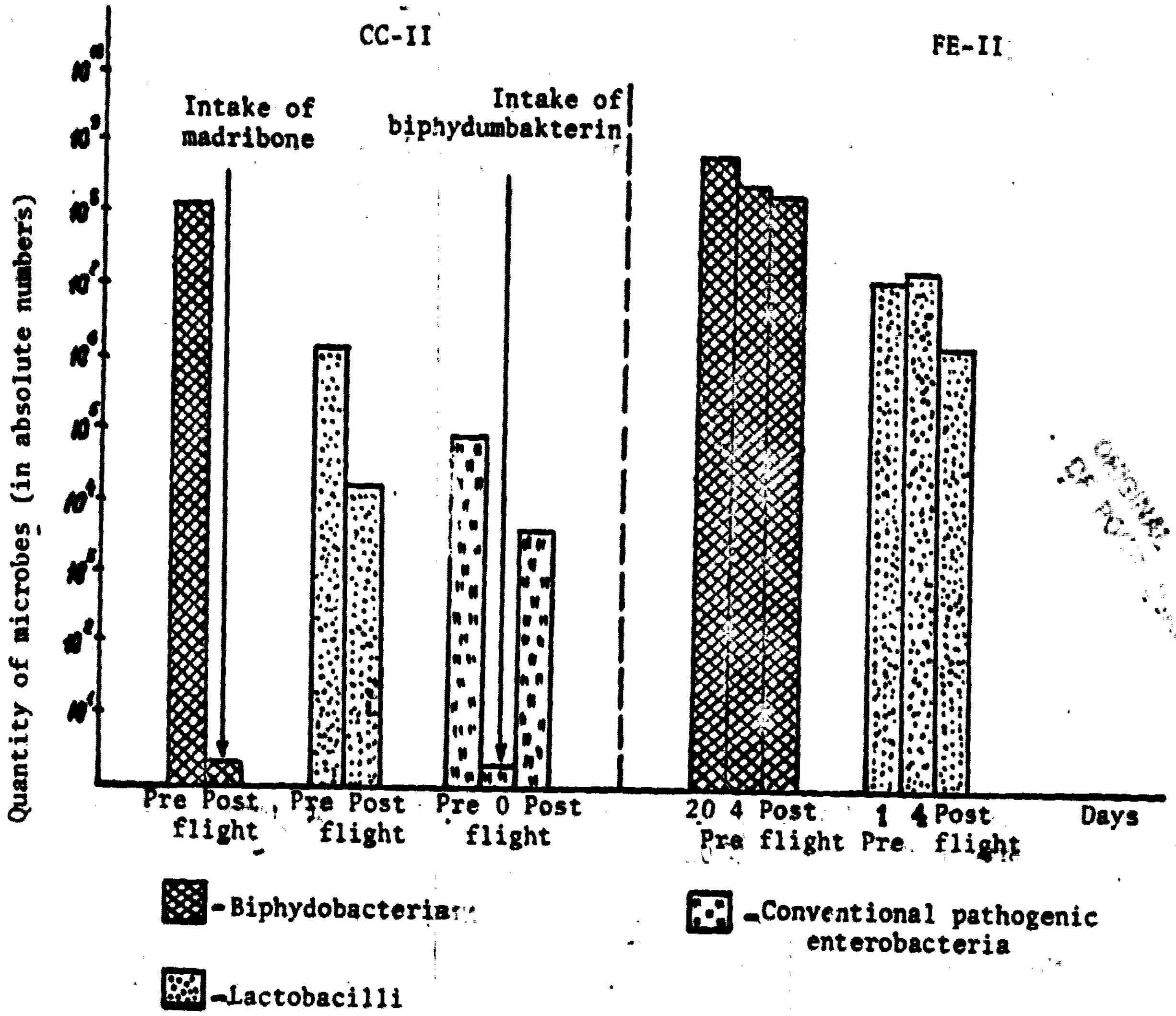

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Figure 1. Change in intestinal microflora in cosmonauts in the 140-day space flight

microflora normal eubiotic ratios were apparent. Here, domination by biphydobacteria over aerobic flora occurred and the content of Escheria, streptococci, Clostridia, Protei and conventionally pathogenic enterobacteria did not exceed the norm established for healthy mature persons. During examination on the 10th and 25th days postflight, certain variations were discovered in the quantitative content of biphydobacteria (toward a decrease) and intestinal bacilli (toward an increase) which caused a breakdown in the relationship between these groups; but the character of these changes did not differ from deviations determined in the preflight period. /278

Thus, the studies showed that in the crew members of the second expedition, in spite of the long duration of the flight, shifts in the composition of the bacteriomicroflora were less pronounced in comparison with changes in the microbiocenosis of the intestines in cosmonauts in the first expedition. The latter were characterized by the following peculiarities. For instance, in the first cosmonaut in the first days after completion of the flight, a sharp increase was apparent in the content of protei (by 1000 times) in comparison with the preflight level recorded for 5 days preflight (Figure 2, CC-I). /279

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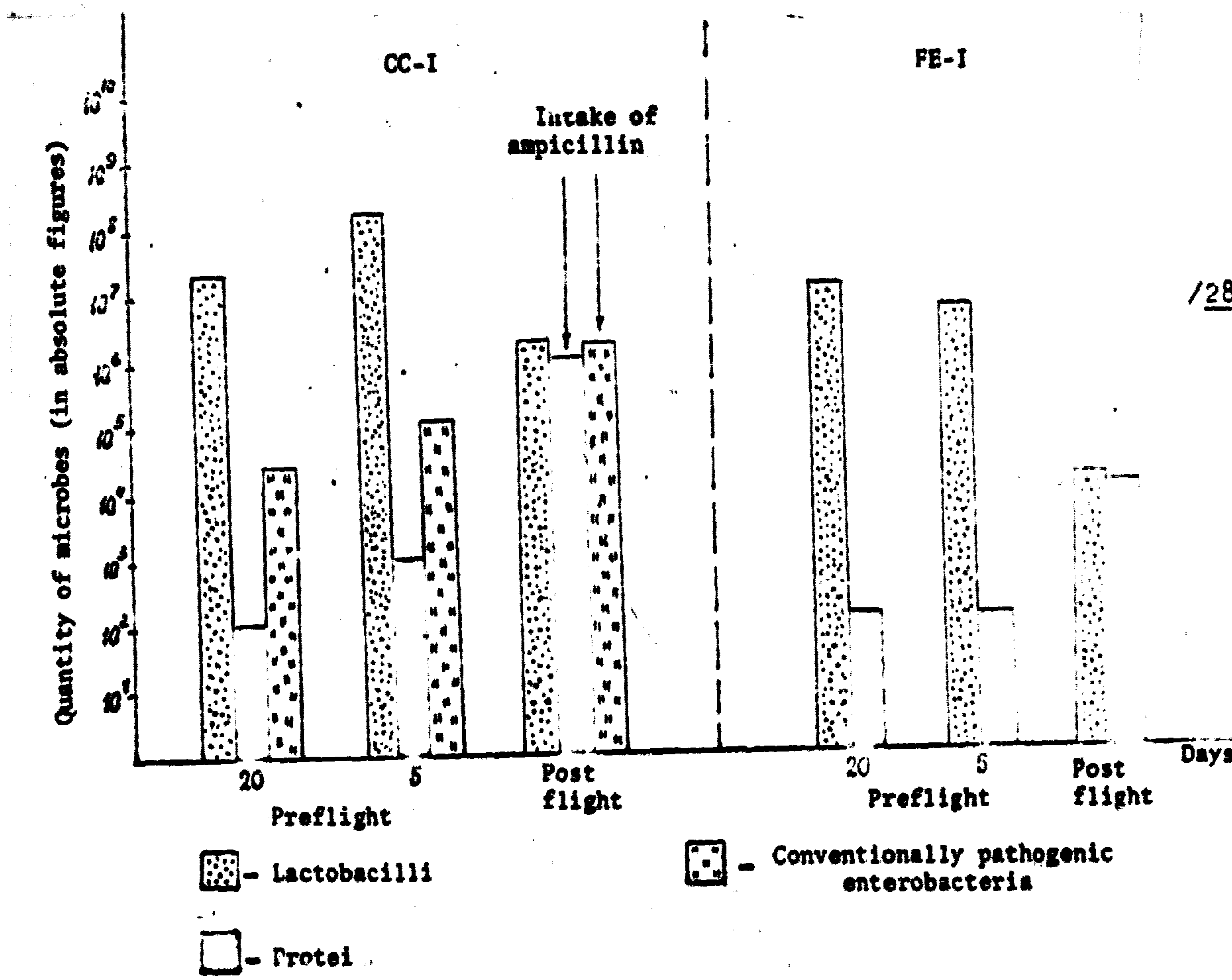

Figure 2. Change in intestinal microflora in cosmonauts during a 96-day flight

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Besides the changes in the indicated groups of microbes, an increase was noted in the content and other conventionally pathogenic enterobacteria in values exceeding the norm. For instance, the content of bacteria of the Ent. cloaccae genus amounted to 5×10^6. Moreover, one should indicate a change in biologic properties of the intestinal bacilli isolated in the cosmonauts postflight. Also a marked decrease in lactobacilli occurred (by 100 times) in comparison with the preflight data. In the second cosmonaut of the first expedition, on the first days after completion of flight, a sharp (by 1000 times) decrease was apparent in lactobacilli and an increase in protei (100 times) in comparison with the preflight data (Figure 2, FE-I). /279

Thus, an absence of marked changes in the aerobic flora of the intestine in cosmonauts after a 140-day flight, apparently is due to intake of the drug Biphydumbacterin in the preflight period. At the same time, probably, the hygienic measures taken were inadequate for maintaining stability of the anaerobic component of biocenosis--biphydoflora in the first CC crew member of the Soyuz-29. Moreover, one should note that during flight, the first cosmonaut took the drug Madribone (sulfodimethoxin) which can facilitate levelling off of the biphydobacteria. In the second cosmonaut, the level of biphydobacteria postflight was not different from the preflight data, which, apparently, was due to the favorable effect of amino acid /281 additives on the state of the biphydoflora; this additive was taken during flight, whereas the first did not receive it at this time (Figure 1).

A similar effect when using vitamin-amino acid additives was achieved by us in crew members of the second expedition of the orbital Salyut-4 station (Figure 3) and also when conducting ground experiments.

A decrease in content of lactobacilli postflight in both cosmonauts is a principle reaction of lactoflora to staying in extreme conditions. On the other hand, one should note an increase in the acid forming activity of lactobacilli which can be considered a compensatory reaction to their quantitative increase.

Taking into consideration the important role of microflora in the protective function, it is expedient to recommend, besides biphydumbacterin, inclusion in the first aid kit onboard of lactobacterin intended for prevention of changes in the lactoflora during antibiotic therapy.

Thus, the data we obtained attest to the good prospects for the drugs used by the cosmonauts (the drug Biphydumbacterin and the vitamin-amino acid supplement), which facilitate normalization and regulation of the composition of intestinal microflora in the conditions of space flight.

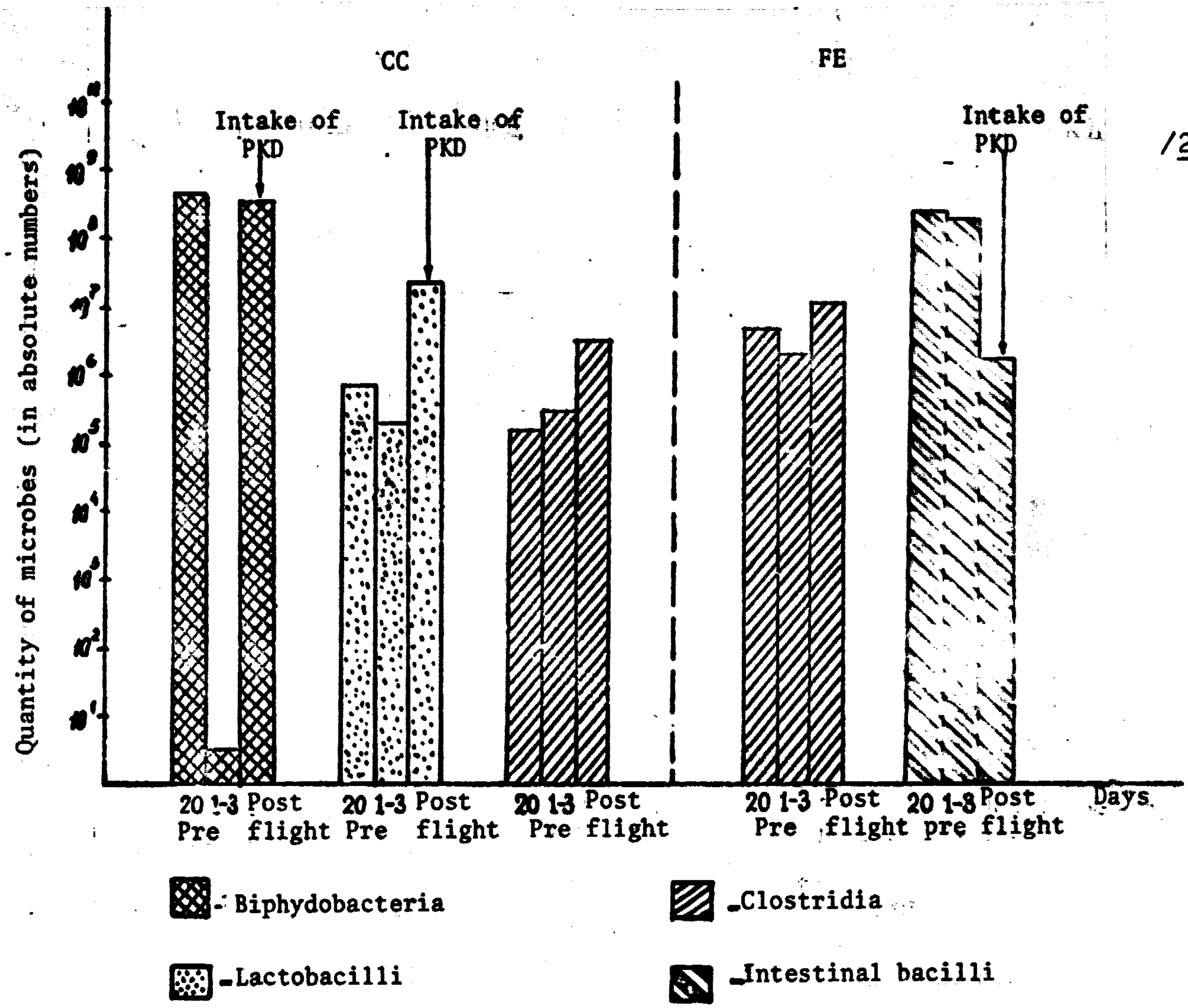

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Figure 3. Change in bacteromicroflora in the cosmonauts in a 63-day flight

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PART V /288

RECOVERY MEASURES IN THE READAPTATION PERIOD

The primary task of the recovery measures after completion of the extremely long 140-space flight was to provide adequate readaptation and more complete and rapid recovery of changed functions and work capability of the cosmonauts. /289

The recovery measures (RM) after the 140-day space flight (SF) were developed on the basis of results of the preceding 62-day and 96-day flights and experimental study and were considered as a continuation of the prophylactic measures taken on board. Depending on the individual peculiarities of the cosmonauts and the vicissitudes of the course of readaptation processes, RM were conducted differently and were corrected daily on the basis of clinical and physiological examinations (CPE) and the subjective state of the cosmonaut.

The use of complex recovery measures whose task was to provide complete and rapid recovery of the changed functions and work capability of the cosmonauts was based on their objective state, previous experience in conducting RM after earlier completed SF and the recommendations developed during experimental studies. The entire complex of RM was conducted in two stages: in stage I for 12 days the RM were conducted at the cosmodrome then on day 27 (stage II) in the sanitorium conditions (Kislovodsk mountains).

Clinical and physiological examination of the cosmonauts after landing showed that they have a marked manifestation of general fatigue and asthenia:

-- detraining of the organism for physical and orthostatic stimuli;

-- the syndrome of residual phenomena of redistribution of blood;

-- statokinetic disorders;

-- decrease in body weight and hypotrophy of muscles of the extremities; /290

-- change in the water-salt exchange with a tendency toward retaining the fluid in the organism;

-- an averaged marked anemic syndrome with manifestation of microcytosis;

-- a decrease in immunoreactive capability of the organism, etc.

Moreover, in the cosmonauts certain peculiarities (differences) were noted in the functional and clinical state. For instance, in one of them in the first hours of days after landing, with statokinetic load, orthostatic and vestibular vegetative changes were predominant showing vestibular discomfort; in the other -- discoordination disorders predominated.

Following is the basis for the RM in the first four days of readaptation:

-- strictly regulated regime of motor activity, orthostatic effects and constant wearing of the space suits;

-- recovery massage of the muscles including manual massage and also morning toning up gymnastics (MTG);

-- short water procedures (warm shower, pool);

-- rational balanced food, rich in vitamins;

-- relaxation autotraining for 20 minutes before sleeping.

Besides the subjective state of the cosmonauts, the indices of the dynamics of pulse and arterial pressure (AP) when carrying out separate procedures and results of CPE were used as the criteria for evaluating the effectiveness and adequacy of the RM conducted.

After conducting the RM listed above for the first two days, the state of the cosmonauts improved: dizziness, general weakness and phenomena of rapid fatigue decreased. Pulse frequency with light orthostatic and physical load (training gymnastics, taking the vertical position in bed) decreased in the first from 100 to 92 and in the second from 80 to 72 beats per minute. The AP figures decreased and became more stable (in the first, from 140/85 to 120/70; in the second, from 130/80 to 110/70). Also vestibular and discoordination disorders decreased. This made it possible at the end of the second day to decide on the first measured walk (200-300 m) in the inflated space suits on the street. Then, the increase in pulse frequency did not exceed 12-20 beats per minute with recovery to initial values in 5 minutes. However, at the end of the day, the cosmonauts noted general fatigue and weariness. /291

The complex RM conducted in the first 2-3 days results in a significant improvement of the state of the cosmonauts, a decrease in the functional and clinical changes apparent postflight. As a whole, this state of readaptation actually did not differ from that noted after less prolonged SF (one month and more).

In the later state of readaptation, the time for MTG was incraased in comparison with that planned earlier and the duration of massage was increased to 60 minutes. From the 5-6 days, RM began be done in the spare time training routine. The length of walks and water procedures was increased. The physiological reactions and transferability of RM were adequate.

From day 9 of the readaptation period, the state of the cosmonauts made it possible to gradually transfer to a training routine for carrying out the RM. In this period, MTG and physical training began to be done in the sports hall; at first the second and then the third peak was maintained on the curve of physical load with an increase in pulse frequency up to 35-40 beats per minute. Walking with an alternating /292 rate for 9-10 km (in 2-2.5 hours) occupied an increasingly important position in the conduct of recovery measures. A recovery massage which included elements of kneading and rubbing followed. The duration of the massage on separate days reached 100 minutes and a frequency of 2-3 times. Massage after physical exercise has the most favorable effect.

Moreover, one should note that the character of recovery of different physiological systems was not uniform either according to the qualitative or the rate index. Significant individual peculiarities and variations (phase aspect) occurred during the readaptation phenomena; however, there were not types of unfavorable clinical manifestations which could force one to change the general direction of the RM. Transferability of load, as a rule, was good and the physiological reactions were adequate. An increase in pulse frequency while walking did not exceed 18-20 beats per minute with subsequent recovery to the initial values in 5 minutes.

On day 12 of the readaptation period, the state of the cosmonauts became fairly good. Moreover, they retained signs of asthenia and a decrease of orthostatic and physical stability, a decrease in tone of the antigravitation muscle, slight discoordination disorders. The speed and power qualities and physical work capability, the picture of peripheral blood were not completely recovered. This required continuing the RM at the sanitorium in a complex using health resort facilities.

On day 16 after landing, the cosmonauts began stage II of RM which was carried out for 27 days in midmountain conditions. At the sanitorium, after a 3 day acclimatization to the midmountains, the cosmonauts conducted a regulated complex RM whose basis was the broad use of health resort facilities. At the end of the stay in the sanitorium, the cosmonauts were considerably strengthened, their general state and physiological indices did not differ significantly from the /293 preflight.

A comparative evaluation of the course of readaptation processes and recovery of functions in the cosmonauts after 140-day and 96-day SF give evidence of a more rapid and qualitatively more complete recovery of the functional state of cosmonauts after the 140-day flight, which, probably is due on the one hand to improved prophylactic measures during flight and on the other in more effective introduction to the readaptation period.

Summary. An analysis of the dynamic clinical observations and results of SPE showed that the gradual conduct of complex RM was fairly effective and as a whole provided, in a comparatively short time period, recovery of the functional state of the cosmonauts.

More valuable means of recovery in the early stages of the readaptation period were the treatment and recovery massage of muscles and water procedures conducted on a background of strict regulation of motor activity and orthostatic effects.

Later on, besides those listed, walking acquired particular importance for the gradual increase in its length, and also therapeutic physical exercise and training.

In the final stage of recovery, the stay of the cosmonauts in the midmountains using health resort facilities had a positive effect.

Measures of autogenic training with effective psychotherapy had an important role at all stages of the recovery period.

Experience in conducting recovery measures confirmed the necessity for strict individualization of the complex depending on the functional and characterologic peculiarities of the cosmonauts, transferability of the procedures (measures) and dynamics of the readaptation reactions.

CONCLUSION /294

A fundamental result of flights of the first and second main crews of the scientific orbital Salyut-6 and Soyuz complex from the medical point of view is that the cosmonauts stayed in orbit for 96 and 140 days; they retained adequate work capability and successfully completed the program laid out for flight which, besides important experiments, was saturated with such complex operations as going outside the spacecraft, joint work with visiting crews, and also work involving cargo spacecraft. All of this is evidence of the fact that man can complete not only long-term space flights but also fulfill a variety of intellectual and physical activity while retaining adequate work capability. Moreover, one must note the high interest, initiative and industriousness of the drews who not only fulfilled the planned program of flights but also used the so-called personal time in a number of cases sometimes limiting the time alotted for sleep in order to conduct initiated, unplanned studies and observations. /295

Flight conditions were characterized by an ordinary two-gas medium similar to the parameters of the Earth's atmosphere, an insignificant value of the radiation effect, the Earth 24-hour cycle of work and rest (Table 1).

The complex of prophylactic means used during flight (Table 2) and the work and rest routine used (Table 1) provided maintaining a good state of health and adequate work capability of the crew in flight and also facilitated leveling off the reactions and making the course of readaptation processes easier in the postflight period. /297

Shifts observed during flight as a whole corresponded to the preflight prediction, reflected the phase character of adaptation processes, had a functional reversible character, and corresponded to effect factors and did not affect the work capability of cosmonauts and the programs completed in flight. The readaptation process after a 140-day flight occurred, as a whole, more markedly than after the 96-day flight.

The period of the first adaptive reactions when transferring to weightlessness were apparent in spatial illusions, a feeling of blood congestion in the head, and in certain cosmonauts vestibular discomfort which usually ended after the first 4-7 days of flight. Later on, the cosmonauts felt well with a few exceptions (Table 3).

Measurement of body mass and volume of the crus showed a decrease of these indices in flight which involves redistribution of the blood and a loss of part of the fluid by the organism and also partial loss of muscle mass and other factors (Table 4).

Studies of the motor apparatus and the system of motor regulation showed: a tendency toward an increase in the electromyographic cost of muscle exertion; changes in the state of the proprioceptor sector inputs and the spinal apparatus reflected in a significant increase in sensitivity to the support and muscle input, decrease in maximum value of the reflector muscle response and disturbance of the

TABLE 1 /296

CHARACTERISTICS OF FLIGHT CONDITIONS ON THE ORBITAL SALYUT-6 AND SOYUZ COMPLEX

1. Gas medium and temperature

- Total pressure -- 733-847 mm mercury column.
- Partial pressure of O_2 158-229 mm mercury column.
- Partial pressure CO_2 1.23-744 mm mercury column.
- Partial pressure of vapors of H_2O 7.0-16.4 mm mercury column.
- Air temperature 19.0-24.5°C.

2. Total dose of radiation

- For the MC-I, 2.1-3.2 bar.
- For the MC-II, 2.9-5.3 bar.

3. Food and water supply.

- Eating four times a day (3100 kcal).
- Protein -- 135 g, fat -- 110 g, carbohydrate -- 380 g, calcium -- 800 mg, potassium -- 3.0 g, phosphorus -- 1.7 g, sodium -- 4.5-5.0 g, magnesium -- 0.4 g, iron -- 50 mg.
- Water supply for MC-I -- 1.2-1.4 ℓ, for MC-II -- 1.4-1.7 ℓ in 24 hours.

4. The routine of work and rest.

- Time for sleep, 9 hours.
- Time for physical training, 2.5 hours.
- Time for food intake, 2 hours and 20 minutes.
- Time for conducting experiments and other work, 8 hours.
- Personal time, 2.0-2.5 hours.
- Days off for the MC-I, every 5-6 days, for the MC-II, every Saturday and Sunday.

TABLE 2 /298

PROPHYLACTIC MEASURES

- Exercises and physical training on the bicycle ergometer and the treadmill (on the average for 10 days of flight the total training time was, for the CC-2, 42-87 min, for the FE-2 -- 51-82 min, daily);

- Wearing the Penguin load suits (12-16 hours out of 24);

- Training with application of negative pressure on the lower part of the body (at the end of flight, according to a special system);

- The use of water-salt additive (on the day of completion of flight);

- The use postflight of prophylactic antiload suits;

- Psychological support and organization of rest time (radio conversations with interesting people, families, musical accompaniment to radio broadcasts, etc.).

TABLE 3 /299

GENERAL STATE OF THE COSMONAUTS

1. In Flight

- The development of feelings of blood rushing to the head, stuffiness of the nose and edema of the face tissue (in all 12 cosmonauts).

- The appearance of short term spatial illusions.

- The appearance in certain cosmonauts of a feeling of vestibular discomfort, increased when moving the head and trunk.

- Poor health, qualified as a cold in one of the MC-I cosmonauts.

- The appearance in the CC-I of headaches and in the FE-I of unfavorable feeling in the region of the heart in the third month of flight briefly which involved lack of sleep.

- Pain in the teeth which occurred in the MC-I.

- In the CC-II, the development of paronychia in the middle finger of the left hand.

- In the FE-II otitis of the middle ear was established retrospectively on day 112 of the flight.

- A bruise on the left ankle joint in the CC-II and the phalanx of the thumb of the right hand in the FE-II when working out on the bicycle ergometer.

- A selected decrease in appetite in the FE-II for certain foods.

- Difficulty in sleeping in the CC-II, particularly in the first 1.5 months of flight.

- Late wakening in the FE-II.

2. Postflight

- Complaints of weakness, fatigue, a seeming increase in body weight and weight of the surrounding objects.

- A distressing feeling of shifting of the organisms in the direction of the gravitation vector.

- A feeling of vestibular discomfort during evacuation from the landing area during sharp motions of the head (in two cosmonauts).

- Paleness of the skin. /300

- Limitation of the locomotor function.

- Decrease in orthostatic stability.

TABLE 4

CHANGES IN BODY MASS AND VOLUME OF THE CRUS IN THE MC-II IN-FLIGHT

Symptom	Possible Mechanisms
- a decrease in body mass reaching its largest values in the CC-II on days 44-59 of flight (-2.3 - -3.4 kg) and in the FE-II on day 86 of the flight (-5.4 kg)	- removal from the organism of part of the fluid; - partial loss of muscle mass; - increased physical activity and emotional stress; - limited intake of food.
- decrease in the volume of the crus in the MC-II in the first 11 days of flight by 11-13%, progressively to days 80-100 in the CC-II to -23.0% and in the FE-II to -19.6%.	- shift in fluid in the cranial direction; - increase in transmural absorption of fluid by the tissue and a decrease in tissue pressure; - a decrease in muscle tone; - a certain loss in muscle mass.

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extremity reflector interactions; disturbance in activity of the posture and locomotor regulation systems. /297

The intensity and duration of shifts in the state of different **members** did not correlate with each other which made it possible to conclude that there was an absence of interconnection in their origin and different mechanisms for their development. The least expressed and shortest **were changes in the muscle length**, and the largest shifts were noted in the system of regulation of whole coordination acts. /302

Studies of the vestibular function and the function of perceiving spatial coordinates showed in the MC-I and MC-II a number of principal changes involving the following: signs of perturbation of of the otolithic organ; a decrease in sensitivity of the cupulary apparatus; asymmetry of the majority of indices studied; development of illusory reactions in flight. Individual reactions were apparent to a different degree in the expression of changes and in different time periods for their recovery, development of vestibular vegative symptom complexes in the period of initial adaptation to weightlessness and the appearance of signs of a decrease in the vestibular and vegetative stability postflight, and also changes in the reciprocal ratio between the otolithic organ and the semicircular canals. As the origin of the changes described of the vestibular function, probably, the most important are such factors as disturbance of the functional system capability in operation of the analyzers, hemoglobin spinal fluid dynamic shifts, etc.

Study of the cardiovascular system in-flight at rest (Table 5) showed a tendency toward an increase in frequency of cardiac contractions and a decrease at certain flight stages of all or several indices of arterial pressure. Blood filling and pressure in the jugular veins **increased**, expandability of the veins of the crus increased. Also a restructuring was noted of the phase structure of the cardiac cycle in the form of shortening the phase of isometric contraction and weakening, lengthening of the period of ejection, shortening of the total diastole and diastasis, increase (only in the CC-II) of relative absolute values of rapid filling. These changes indicated /305 an increase in power and effectiveness of cardiac contractions and an increase in the role of the suction function of the heart (active diastole) in hemodynamics as a result of the decrease in pressure gradient in the venous system.

The indices of the central and regional hemodynamics were characterized by tendencies toward an increase in minute volume of blood circulation, an increase in the indices of pulse and minute blood filling of the head (which were retained for the entire 96-day flight and leveled off at the end the 140-day flight) and a decrease in blood filling of crus.

Bioelectrical activity of the myodardium in flight changed insignificantly but postflight one noted a decrease in the integral vector of depolarization.

TABLE 5

RESULTS OF STUDIES OF HEMODYNAMICS AT REST IN THE MC-I AND MC-II IN-FLIGHT

Symptoms	Possible Mechanism
Arterial pressure	
- Arterial pressure in a number of cases at certain stages have a tendency toward decrease of all or certain indices	An increase in tone of the vagus and involvement of tension reflexes with receptors of the pumonary vessels.
The phase structure of the cardiac cycle (MC-II)	
- Shortening of the phase of isometric contraction and weakening; - lengthening of the period of ejection; - shortening of the total diastole and diastasis; - decrease (only in the CC-II) of relative and absolute values of rapid filling.	- load on the heart by volume; - increase in the role of the suction function of the heart as a result of a decrease in the pressure gradient in venous system.
Indices of central and regional hemodynamics	
- Stroke volume of the heart increased in the first week of flight in 3 of the 4 cosmonauts (by 20-32%); - minute volume of blood circulation had a tendency to exceed the preflight values for the entire extent of the flight; - indices of pulse and minute blood filling of the head were increased and only decreased at end of the 140-day flight.	- shift in fluid in a cranial direction;

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Symptoms	Possible Mechanism
Venous system	
- Venous pressure in the jugular vein was increased for the entire length of the flight, to the greatest degree in the MC-I; - venous pressure in the region of the crus on days 120-130 amounted in the CC-II to 8 mm Hg, and in FE-II -- 6 mm Hg; - the tone of the crus vein decreased and their expandability increased.	- Shift of the fluids in a cranial direction; - development of the phenomena of general venous stagnation as a result of the decrease in the pressure gradient in the venous system and, possibly, as a result of a decrease in activity of the intromuscular peripheral centers; - decrease in muscle tone; - decrease in tissue pressure.
Bioelectrical activity of the myocardium	
- integral vector of repolarization postflight somewhat decreased and not fully recovered in a month; - integral vector of depolarization postflight corresponded to the preflight value.	- development of the phenomena of vegetative imbalance; - metabolic and electrolytic shifts; - physical training.

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Echocardiographic examination showed postflight in both crews a decrease in the final diastolic volume of the left ventricle and stroke ejection, an increase in diameter of the left auricle. These changes were reversible and more rapidly recovered in the MC-II, (in the period of a week). /305

A test with measured physical load (750 kgm/min for a period of 5 min) caused, in flight in both crews (MC-I and MC-II) more pronounced reactions of cardiohemodynamics than preflight. This was apparent in a large increase in the frequency of cardiac contractions (particularly in the 96-day flight), more marked changes in the phase structure of the cardiac cycle and arterial pressure, an increase in the role of the chronotropic function of the heart information of cardiac ejection.

To a more marked degree the increase in reaction of the cardiovascular system to the test as a whole was detected in the MC-I and more significant shifts in the indices of blood circulation in flight tests was noted in the FE-I. The indicated changes were considered as signs of detraining of the organism caused by lack of load on its main systems. The relative decrease in work capability had individual peculiarities. It was greater in the MC-I in tests during the first month of flight and in the FE-I practically for the entire extent of the expedition, which apparently, is explained by the small volume of physical exercise of this cosmonaut. In the MC-II, the reactivity of the circulatory system did not change did not change significantly; however, signs of detraining were apparent. /306

Postflight a test with measured physical load was conducted on day 7 (one stage 600 kgm for 3 minutes) and showed changes in regulation of the cardiorespiratory system. Then, in the MC-I the frequency of cardiac contractions and the systolic arterial pressure increased during the test in comparison with the preflight data. The product of these indices (the so-called cardiac load index according to I. K. Shkhvatsabaya) increased in the commander by 10% and in the flight engineer by 28%. This increase in cardiac activity provided an adequate demand for oxygen only in the commander and in the flight engineer was 11% lower than the preflight which, obviously, expressed detraining for physical load. In the MC-II, one noted an increase in the directivity of cardiac activity even at rest: the cardiac load index exceeded the preflight values in the CC-II by 44%, in the FE-II -- by 75%. However, the reaction itself to physical load taking into account the initial level, changed to a lesser degree: the cardiac load index increased during the test in the CC-II by 20%, and in the FE-II by 34% in comparison with its preflight value. Although the intensity of cardiac activity was increased, it provided an adequate demand for oxygen and consequently, reflected primarily a change in regulation of the cardiorespiratory system. After five weeks of readaptation, reaction to physical load was fully recovered. /307

One can assume that the main factors causing a decrease in transferability of the tests with physical load is the development of a general detraining in the organism as a result of inadequate load on the muscle system in flight and also difficulty postflight in venous return.

The functional test with application of negative pressure on the lower part of the body (LBNP) caused a reaction similar, as a whole, to the preflight (increase in frequency of cardiac contractions, increase in diastolic and decrease in systolic arterial pressure, development of a phase syndrome of functional hypodynamia of the myocardium, decrease in indices of cardiac ejection and pulse blood filling of the vessels of the brain). However, an increase in frequency of cardiac contractions in most cases in-flight was more marked, with a weakly expressed tendency toward its increase in certain cosmonauts depending on duration of the flight. As a whole, the expression of change when carrying out tests with LBNP in the MC-II was smaller than in the MC-I.

In the postflight period, a study was made of the reaction of the organism to orthostatic and anti-orthostatic effects according to the following system: horizontal position -- 30 minutes, 70° -- 10 minutes, horizontal position -- 6 minutes, -15° -- 6 minutes, -30° -- 6 minutes. In all cosmonauts, a decrease in orthostatic stability was apparent (Figure 11) in a larger than preflight increase in frequency of cardiac contractions, shortening of the ejection period, a decrease in stroke and cardiac index. A decrease in orthostatic stability in the MC-II was more persistent (7 weeks) than in the MC-I (3 weeks). Attention should be given to the peculiarity of orthostatic reactions /308
after these flights. After the 96-day flight, after 3 and 5 weeks hypertension reactions were observed and after the 140-day flight the opposite tendency was noted. This can be reevaluated as a sign of a more persistent suppression of the antigravitational function of the system of blood circulation in the longer flight.

An increase in expression of reactions in the LBNP test in flight can be due to the larger, than on Earth, shift in the blood to organs of the abdominal cavity and lower extremities when creating a stimulus resulting in a decrease in activity of the receptors of the cardiac-pulmonary region and an increase in activity of the vasomotor center with an increase in adrenergic effects. Other factors which decrease transferability of the tests with LBNP and ortho-tests are: an increase in expandability of the veins of the lower extremities, a decrease in the quantity of circulated blood, a decrease in the content of intertissue fluid, a decrease in vascular and muscle tone, a decrease in catecholamine exchange, a decrease postflight in venous return and others.

After the flights, all of the cosmonauts endured anti-orthostatic load better subjectively, noting a decrease in its "load" by approximately 15°. According to integral evaluation, based on the values of the cardiac cycle, arterial pressure and tone of the main arteries, the anti-orthostatic stability increased in all the cosmonauts and gradually over 5 weeks of observation returned to its initial level.

Thus, in long-term flights, the system of blood circulation adapts to weightlessness which is apparent in the increase in capability of counteracting redistribution of blood in the cranial direction. The expression of adaptive changes depends on the individual plasticity of the blood circulation system and their persistence on duration of the flight. /309

A study of the character and direction of exchange processes in the cosmonauts made in the 140-day space flight showed the presence only of insignificant restructuring of the main processes of metabolism, the physiologically based necessity for maintaining homeostasis in unusual conditions of space flight. No signs of marked disturbances in exchange of substances has been established. In the first days after landing a tendency was clearly noted toward a change in the ratio of the main paths of the metabolism expressed in predominant use energetically of more convenient oxidation conversions of fats. This conclusion, and also the data on which it is based do not coincide with results obtained during biochemical studies of the cosmonauts after completion of the 96-day space flight. One should note that changes in the processes of metabolism in the cosmonauts after completing the 140-day space flight were less pronounced than in cosmonauts who had completed the 96-day space flight.

The different results obtained immediately after landing of the 96-day and 140-day flights are not random. They can be explained by the phase character of processes of adaptation of the organism to the conditions of space flight. Obviously, the moment of completion of the 96-day and 140-day flights occurs at different stages of this adaptation. In spite of this, the character and course of readaptation processes, according to the data of biochemical studies were similar in crew members of the two long-term space expeditions. Almost complete normalization of metabolic homeostasis was noted by the 25th day (2 main expeditions) and on the 32nd day (first main expedition) after completion of the space flight.

Studies of water-salt exchange and kidney functions showed immediately after landing a decrease in excretion by the kidneys of fluid in three cosmonauts (except for the CC-II who in the final stage of flight did not take the water-salt additive) on a background of increase of water demand, a decrease in the rate of excretion of sodium. On the day of landing, the rate of excretion of potassium also decreased and here the absolute values of generation of potassium increased and were higher than its intake into the organism. The negative balance of potassium, probably, is due to a decreased cellular mass and cannot be compensated for by increasing its intake. In the MC-I, postflight, excretion of potassium increased both in the daily urine and after a water load. After the 140-day flight, in both cosmonauts, to a larger degree in the FE-II, during the test with calcium lactate, its rate of excretion also was significantly higher than the initial. The concentrations of ions in the blood serum hardly differed from the preflight level except for an increase in the ionized fraction of calcium. During clinical analysis of the urine samples collected during flight, no pathological changes were apparent. The changes noted in mineral exchange probably as a whole were caused not by a disturbance in activity of the kidneys but were the result of peculiarities of the hormonal regulation during a long term stay of man in weightlessness conditions and after transition to Earth's /310 gravitation. It was also established that with an increase in the duration of the flight up to 140-days, the value of hypohydration does not increase.

<u>Hematologic studies</u> showed after the flights in both crews a de-
crease in the total mass of hemoglobin (in the MC-I by 24%, in the
MC-II -- by 15-17%), a decrease in the quantity of erythrocytes (a
more marked decrease was observed in the MC-II not immediately but
some time after completion of the flight: in the CC-II on the
20th day, and in the FE-II on the 34th day) and the content of hemo- /311
globin. After the 96-day flight, changes were apparent in the value
and shape of erythrocytes (aniso- and poikilocytosis) which amounted
to 15-20% of the normal shapes. The primary decrease in the number
of reticulocytes shifted toward further pronounced reticulocytosis.
However, recovery of the red blood occurred slowly (particularly in
the MC-II) which, apparently indicated slowing down of maturity of
the young forms of erythrocytes in the bone marrow.

A study of kinetics of erythrocytes showed prolongation of time periods for their circulation in flight and contraction of the duration of their life just a month after landing; this indicates restructuring of erythropoiesis in weightlessness. On the first days after landing, in the MC-II, also a decrease in the indices of energy exchange was apparent in the erythrocytes: the content of ATP decreased by 25-43%, and the intensity of glycolysis -- by 38-42%, the content of glutathione -- by 2 times. It is possible that the decrease of energy exchange involves the formation of new forms of erythrocytes in conditions of weightlessness with long duration of life and low level of exchange.

The volume of intracellular fluid in both crew members decreased and this decrease was more pronounced after the 140-day flight and amounted in the CC-II to 14%, in the FE-II to 8.2%.

<u>Immunologic studies after a 140-day flight</u> showed significant changes in the content of the thymus dependent lymphocytes (a decrease in the level of the total population of T-lymphocytes on a background of an increase of "active" T-cells) and a sharp drop in functional activity of the T-lymphocytes.

In the flight engineer, disgammaglobulonemia was noted (a sig-
nificant drop of the content 1 SH and an average decrease in 1A in
the blood). In one of the cosmonauts, the appearance postflight of /312
hypersensitivity of a slow type to bacterial allergens (staphylococcus
and streptococcus) was established. When setting up allergologic
tests in the postflight period, in a number of allergens of chemical
origin, in both cosmonauts one notes the presence of sensitivity to
formaldehyde (a positive reaction to agglomeration) confirmed in one
of them also by the appearance of the corresponding lymphokines
(positive reaction of MIF with formaldehyde, ++). Thus, after the
140-day flight, a number of shifts are apparent which indicate a
change in the immunologic reactivity like that observed earlier after

30-day and 63-day space flights. Moreover, after the 96-day flight these changes were less pronounced. Because of this, one can assume that the process of adaptation of the immunocomponent system to conditions of space flight occurs in phases and after the primary adaptation for 2-3 months, later on secondary shifts occur. However, this supposition requires additional study in long-term space flights.

Microbiological studies indicated that in the MC-II, in distinction from MC-I, when carrying out a study of microflora of the respiratory tracts and skin during flight, there were no unfavorable changes established. In other words, a direct relationship between the markedness of the shifts in a state of automicroflora of the skin of cosmonauts and long-term flight has not been apparent. Obviously, the factor that individual peculiarities peculiar to the cosmonaut in microbiological status is the basic factor here as well as the markedness of adaptation reactions to conditions of space flight, the volume and character of methods used for personal hygiene, measures for maintaining sanitation and hygienic routines. In spite of the /313 longer flight, the cosmonauts in the second expedition had no disturbance in the aerobic flora of the intestine whereas in the MC-I changes were recorded in the state of the intestinal microflora with the development of protein disbacteriosis. It is proposed that for normalization of microflora of the intestine, the use by the cosmonauts in the second main expedition of the drug Bifidumbacterin and a vitamin-amino-acid additive played a positive role.

In conclusion one can point out that the changes observed after the completion of the 140-day space flight in the organism of the cosmonauts showed reactions characteristic for the readaptation period and, as a whole, were somewhat less pronounced than after a 96-day flight.

Clinical and special studies conducted in the first hours and days after completion of the flight showed the following changes:

-- general fatigue and asthenia of the organism apparent in rapid physical and psychological fatigue, an increased irritability emotional lability, sleep disturbances (in the commander) and a marked general physical weakness (in the flight engineer);

-- detraining of the organism to orthostatic and physical effects;

-- aftereffects from redistribution of blood in the upper half of the body;

-- statokinetic disorders;

-- hypotrophy of the muscles of the lower extremities and a loss /314 of body weight;

-- an average anemic syndrome apparent;

-- change in the water-salt exchange with a tendency toward retaining fluid in the organism;

-- a decrease in immunologic reactivity.

Methods of functional effect were included as the basis for the complex of recovery measures; among these the following are the most important: regulation of motor activity; treatment-recovery massage of the muscles; therapeutic physical exercises and measured walking water procedure; measures for psychoemotional effects. The effectiveness of the measures taken was evaluated by subjective perceptions, the dynamics of pulse and arterial pressure when carrying out procedures and according to the results of clinical and physical examinations.

After the 140-day flight, the recovery measures were carried out in two stages: the first stage (2 weeks) in the cosmodrome and the second stage (4 weeks) in mountains of average altitude (Northern Caucusus).

One should note that the studies made during and after flight did not show changes in general health which would prevent a further planned increase in duration of space flights.