N80 23115

NASA TECHNICAL MEMORANDUM NASA TM-76036

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Translation of "Krovoobrashcheniye v usloviyakh nevesomosti," Izvestiya Akademii Nauk SSSR, Seriya Biologicheskaya, No. 3, 1964, pp 352-368

(NASA-TM-76036) BLOOD CIRCULATION UNDER CONDITIONS OF WEIGHTLESSNESS (National Aeronautics and Space Administration) 25 p HC A02/MF A01 CSCL 06S

N80-19786

Unclas G3/52 47447

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 MARCH 1980

BLOOD CIRCULATION UNDER CONDITIONS OF WEIGHTLESSNESS

I. I. Kas'yan, V. I. Kopanev and V. I. Yazdovskiy

In studying the effect that weightlessness conditions have on humans their influence on blood circulation has always attracted the attention of researchers, /352* since in great part the functional condition of the cardiovascular system and hematopoietic organs dictates the life and work capacity of the organism. For this reason it would seem, that in nearly all works devoted to the problem of weightlessness, whether in animals or in humans, there has been a study of the cardiovascular system.

In recent years Soviet researchers have gathered a good deal of material on the effect of weightlessness on the circulatory system of humans and animals (Bugrov et al., 1958; Galkin et al., 1958; Chernov, Yakovlev, 1958; Antipov et al., 1962; Balakhovskiy et al, 1962; Gazenko, 1962; Kas'yan, 1962, 1963a, b, c; Kas'yan et al., 1962; Parin et al., 1962; Sisakyan, Yazdovskiy, 1962, 1964; Yakovlev, 1962; Akulinichev et al., 1963; Pavlov, 1963, etc.)

Nevertheless until now there have not been any generalized communications, although the need is perfectly obvious. The authors of the present work have attempted to fill this gap. In doing so they have made use both of their own findings and data in the literature.

As we know, the study of the effect of weightlessness on the human and animal organism depended in great part on the possibility of creating longterm weightlessness conditions. At the start the situation was modeled on terrestrial setups (Lomonaco et al., 1957; Gurfinkel et al., 1959) and later researchers began to use different types of flying equipment. Tables 1 and 2 show the basic stages in the conquest of circumterrestrial space by the Soviet Union. A strict sequence was observed in the study of circumterrestrial space both in respect to the term of weightlessness and in regard to the objects studied (animal experiments and then those involving human participation), as well as gradual broadening of the methods for in-

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

TABLE 1. BASIC STAGES OF MASTERY OF CIRCUMTERRESTRIAL SPACE WITH ANIMALS /353

Nature of flight	Launching date	Object studied	Time spent in weightlessness	Indices of functional condition of cardiovascular system
Suborbital up to				
100-110 kg	1949-1956	26 dogs	3.7 min	Pulse rate, BP
210-212 kg	1956-1960	20 dogs	6.0 min	Pulse rate, BP, bioelectric cardiac activity (EKG 2 leads)
Orbital up to				
450-473	1958-1959	6 dogs	9.0 min	same as above
"	3 Nov. 1957	Layka	Whole flight	as above (EKG chest lead)
"	19 Aug. 1960	Belka, Strelka	25 hrs	as above (EKG chest leads), phonocardiogram
"	1 Dec. 1960	Pchelka, Mushka	25 hrs	Pulse rate, bioelectric cardiac activity (EKG), phonocardiogram, seismocardiogram
"	9 Mar. 1961	Chernushka	65 min	Pulse rate, cardiac muscle biopotential (EKG 2 leads), sphygmogram
"	22 Mar. 1961	Zvezdochka	65 min	same as above

vestigating the cardiovascular system, which made it possible to form a better founded judgement about some physiological mechanisms of blood circulation in weightlessness. Reference should be made to the long period of terrestrial research during which systems were devised for taking care of the life and safety of animals and humans and without which there would have been no thought of launching Soviet aircraft into the proximal part of space with success. In almost every flight experiment, in addition to biological objects of study referred to, there were usually small animals (guinea pigs, rats, mice, etc.). They were used to work out a number of special problems associated with prolonged weightlessness as it affects various bioprocesses.

TABLE 2. BASIC STAGES OF MASTERY OF CIRCUMTERRESTRIAL SPACE WITH HUMANS

Nature of flight	Launching date	Object studied	Time spent in weightlessness	Indices of functional condition of cardiovascular system
On aircraft tracing parabola of weightlessness	1960-1964	Test astronauts	Up to 45 seconds	Pulse rate, BP, biopotentials of cardiac muscle (EKG), cardiac tones (phonocardiogram)
Orbital flight	12 June'61	Yu. A. Gagarin	64 min	Pulse rate, biopotentials of cardiac muscle (EKG)
"	6 Aug. 1961	G. S. Titov	25 hrs	As above + kinetocardiogram
"	11 Aug. 1962	A. G. Nikolayev	95 hrs	As for Gagarin
"	12 Aug. 1962	P. R. Popovich	71 hrs	As above
"	14 June 1963	V. F. Bykovskiy	119 hrs	As above + seismocardiogram
"	16 June 1963	V. V. Tereshkova	71 hrs	As above

Tables 3-5 present data on changes in some physiological indices of dogs during suborbital flight to an altitude of 100-473 km. During weightlessness these animals presented a lower pulse rate and blood pressure that regularly lasted till the end of the weightless condition. During the first half of the weightless period in respect /354 to data gathered when the ship was put into orbit the pulse rate was faster in 6 cases, slower in 12 and unchanged in 4. During the second half of the weightless period most of the measurements showed a pulse rate the same as the initial rate (Table 3). In respect to the direction taken by the physiological reactions the animals /355 may be divided into three groups: 1) the group with distinct lowering of pulse rate and BP; 2) the group with no noticeable changes in the indices referred to; 3) the group with increased pulse rate and BP. The first group was the most numerous.

V. V. Yakovlev (1962) in a study of the condition of the peripheral blood circulation before, during and after flight in geophysical ballistic rockets launched into the upper layers of the atmosphere found, that the animals' maximal arterial and venous pressure and rate of blood flow underwent no change. There were no significant

TABLE 3. CHANGES IN PULSE RATE (BEATS/MIN) AND BP (MM Hg) IN DOGS DURING WEIGHTLESSNESS (UP TO 690 SEC) COMPARED WITH DATA RECORDED AT THE END OF ACTIVE PARTICIPATION

a	b	c		d	e: f			e: g		
					h	i	j	k	l	m
100—110	8	Частота пульса	n	60—170	2/15—47	4/10—32	2/0	1/75	—	6/0
		Максим. уровень кровяного давления	o	130—170	—	2/15—42	2/0	—	—	—
		Миним. уровень кровяного давления	p	60—75	—	3/12—15	1/0	—	—	—
200—212	10	Частота пульса	q	115—265	4/12—22	4/15—127	2/0	2/60—80	—	6/0
		Максим. уровень кровяного давления	r	200—240	—	4/20—40	—	—	2/15—30	2/0
		Миним. уровень кровяного давления	s	55—70	—	—	1/0	—	3/15—20	2/0
450—473	6	Частота пульса	t	160—210	—	4/20—65	—	1/40	—	5/0
		Максим. уровень кровяного давления	u	188—265	—	5/15—35	—	—	2/20—30	—
		Миним. уровень кровяного давления	v	105—138	—	1/20	2/0	—	—	2/0

W. Примечание. [illegible]

Key:
- a. Flight altitude in km.
- b. Number of dogs.
- c. Physiological indices.
- d. Initial data (moment of entry into orbit).
- e. Weightlessness.
- f. First period.
- g. Second period.
- h. Increase. (also k)
- i. Decrease. (also l)
- j. Unchanged. (also m)
- n. Pulse rate. (also q, t)
- o. Maximum BP (also r, u)
- p. Minimum BP (also s, v)
- w. Remark:
  numerator = number of changes produced;
  denominator = range of changes in indices under study.

disruptions in peripheral vessels except for a decrease in vascular tone.

G. I. Pavlov (1963), when studying arterial and venous pressure in intact and delabirynthed animals (dogs), in an acute experiment under conditions of weightlessness (Keller's parabola) found out, that in intact animals at the beginning of the condition maximal and minimal arterial pressure dropped 20-40 mm Hg, while venous pressure in the right atrium dropped 15-25 mm Hg. Toward the end of the weightless period (seconds 25-30) arterial pressure returned to the initial figure; venous

TABLE 4. CHANGES IN ARTERIAL BLOOD PRESSURE (MM Hg) AND PULSE RATE IN ANESTHETIZED ANIMALS DURING SUBORBITAL FLIGHT UP TO 210-212 KM

a Кличка собаки	b Показатели	c За 30 сек. до старта	d Невесомость (время в сек.)		
			[illegible]	17—25	26—44
e Белка	f Частота пульса	90	84—90	90—96	84—90
	g Артериальное давление (максим.)	—	85—90	90	80—90
h Модница	f Частота пульса	210	216	200—192	188—180
i Пальма	f Частота пульса	120	140—145	145	145
	g Артериальное давление (максим.)	172—220	200—180	180—170	—
	g' Артериальное давление (миним.)	—	110—155	100—110	100—110

Key: a. Name of animal.
b. Indices.
c. 30 sec before start.
d. Weightlessness (sec).
e. Belka.
f. Pulse rate.
g. BP (max).
g' BP (min).
h. Monnitsa.
i. Pal'ma.

TABLE 5. CHANGE IN LEUKOCYTE COUNT IN EXPERIMENTAL ANIMALS BEFORE AND AFTER SUBORBITAL FLIGHTS

b Кличка собаки	a Число лейкоцитов в 1 мм³		
	c накануне полета	d через 1,5—24 часа после полета	e величина изменения
100—110 км			
Линда f	8400	9100	+ 700
Малышка	9400	14 000	+ 4600
Альбина	15 000	14 600	— 400
200—212 км			
Рыжая g	18 700	39 800	+ 20 200
Дамка	8300	21 100	+ 12 800
»	11 300	13 800	+ 2500
Белка h	11 200	13 800	+ 2600
»	11 640	13 400	+ 1760
Модница i	13 000	14 200	+ 1200
Пальма	11 400	14 800	+ 3400
»	15 200	19 600	+ 4400
Снежинка j	7500	9300	+ 1800
Отважная	13 700	23 900	+ 10 200
»	7000	12 500	+ 5500
»	7250	18 300	+ 11 050
450—473 км			
Пестрая k	9100	18 800	+ 9700

Key: a. Leukocyte count/mm^3.
b. Name of animal.
c. Eve of flight.
d. 1.5-24 hr post-flight.
e. Degree of change.
f. Linda, Malyshka, Albina.
g. Ryzhaya, Damka (2x).
h. Belka (2x).
i. Monnitsa, Pal'ma (2x).
j. Snezhinka, Otvazhnaya (3x).
k. Pestraya.

TABLE 6. CHANGES IN PULSE RATE (BEATS/MIN) AND BP (MMHg) IN TEST SUBJECTS (83 PERSONS) DURING HORIZONTAL FLIGHT AND AFTER PARABOLIC WEIGHTLESS FLIGHT COMPARED WITH INITIAL FIGURES AND DURING WEIGHTLESSNESS IN RESPECT TO RESULTS OF OBSERVATION DURING HORIZONTAL FLIGHT

a	b			c						d		
				e			f					
	g	h	i	g	h	i	g	h	i	g	h	i
					j Частота пульса							
[illegible]–82	[illegible]/[illegible]	68/5–12	36/0	15/5–[illegible]	[illegible]/[illegible]	64/0	63/5–[illegible]	[illegible]/5–30	38/0	21/5–15	105/25	41/0
					k Артериальное давление (максимальное)							
110–165	58/5–1[illegible]	28/5–2[illegible]	6/0	15/5–2[illegible]	[illegible]/[illegible]	7/0	—	2/5–20	1/0	26/5–15	84/10	51/0
					l Артериальное давление (минимальное)							
53–87	31/5–15	22/5–22	12/0	12/5–10	43/5–20	10/0	1/15	2/5–10	—	62/5–30	20/10	7/0

m [illegible]

Key:
a. Initial pre-flight data.
b. During horizontal flight.
c. Weightlessness.
d. Post-flight.
e. First half.
f. Second half.
g. Increase.
h. Decrease.
i. Unchanged.
j. Pulse rate.
k. Arterial pressure (maximal).
l. Arterial pressure (minimal).
m. Remark:
numerator = number of changes produced
denominator = range of changes in indices under study

pressure was rising slightly but remained below initial values. Delabyrinthed dogs showed no significant changes. The author associates these reactions with the function of the vestibular analyzer.

In a number of experiments aimed at clarifying some physiological mechanisms research was done on anesthetized animals. Under anesthesia they showed no pronounced changes in pulse rate and BP (Table 4). This speaks for the important role of the extero- and interoceptive reflexes and of the functional condition of the higher portions of the central nervous system in forming physiological reactions. Analogous results were obtained in the work of Henry et al. (1952), who conducted experiments with anesthetized monkeys in rocket flights up to 60–120 km. There was no sign of real disturbance in autonomic functions, although during weightlessness arterial and venous pressure tended to decrease.

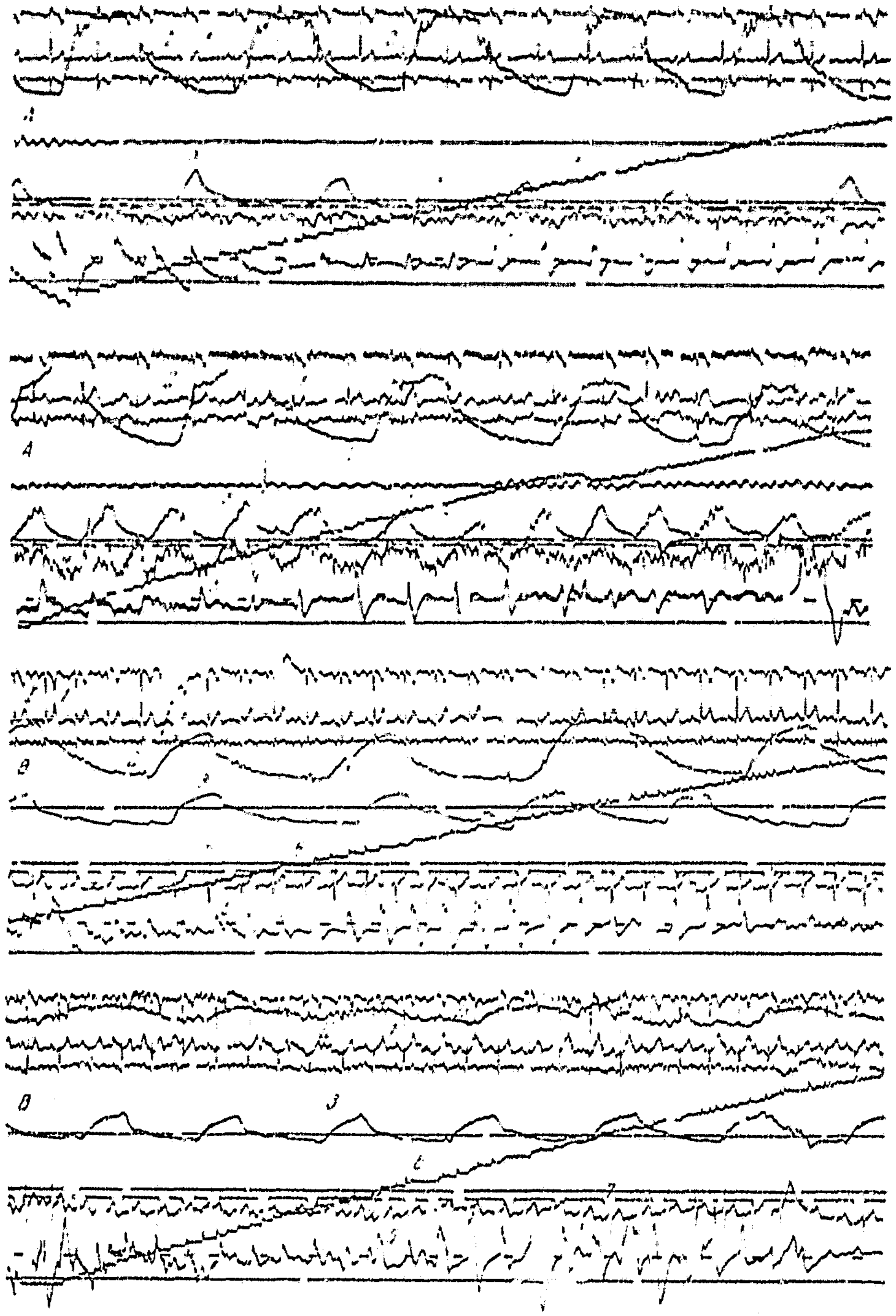

Fig. 1. Recordings of physiological reactions in astronauts (A) Yu. A. Gagarin and (B) A. G. Nikolayev in preflight period and during weightlessness: 1 - background-earth; 2 - astronaut's respiration rate; 3, 4 - respiration rate and EKG of flight pilot; 5 - oscillation of astronaut; 7 - time indicator.

TABLE 7. CHANGE IN PULSE RATE (BEATS/MIN) IN DOGS DURING LONGTERM WEIGHTLESSNESS

a	b	c		d									
				e									
		f	g	2	[illegible]	1	5	[illegible]	[illegible]	1[illegible]	14	15	16
h Стрелка	M	85	72	69	70	75	79	85	113	121	104	117	88
	σ	—	7,0	1,8	11,[illegible]	7,9	17,8	21,8	18,1	11,5	14,0	17,3	21,1
Белка	M	70	62	70	60	74	64	18[illegible]	136	85	71	92	74
	σ	—	11,0	6,7	8,1	8,2	[illegible]	27,[illegible]	13,[illegible]	4,7	6,[illegible]	15,[illegible]	5,5
Пчелка	M	86	119	88	86	74	71	8[illegible]	77	80	66	60	67
	σ	19,7	11,1	12,[illegible]	10,[illegible]	13,4	7,7	8,0	8,5	—	—	—	—
Мушка	M	83	120	108	117	104	100	93	94	106	80	95	87
	σ	21,6	8,7	25,0	8,0	7,1	5,[illegible]	15,4	14,[illegible]	—	—	—	—

i. [illegible]

Key: a. Name of dog.
b. Indices.
c. Initial prestart data.
d. Weightlessness.
e. Earth orbits (helical).
f. 4 hours.
g. t minutes.
h. Strelka, Belka, Pchelka, Mushka.
i. M = arithmetic average
sigma = mean square deviation

TABLE 8. CHANGE IN SOME INDICES OF EKG IN DOGS DURING LONGTERM WEIGHTLESSNESS (INTERVALS PQ, QT IN SECONDS; AMPLITUDE OF R_1, T_1, R_1 IN PROPER UNITS; SYSTOLIC INDEX IN %) (AVERAGE FINDINGS)

a	b	c		d									
				e									
		f	g	2	[illegible]	4	5	[illegible]	7	1[illegible]	14	15	16
h Стрелка STRELKA	PQ	0,11	0,15	0,11	0,11	0,11	0,10	0,10	0,09	0,09	0,08	0,10	0,10
	QT	0,25	0,43	0,25	0,24	0,23	0,24	0,23	0,25	0,25	0,25	0,22	0,23
	P_1	—	—	0,19	0,18	0,20	0,21	0,18	0,20	0,21	0,19	0,18	0,19
	R_1	—	—	1,0[illegible]	1,01	0,82	0,99	0,90	0,87	0,98	0,91	0,89	0,93
	T_1	—	—	0,11	0,14	0,13	0,17	0,13	0,13	0,23	0,17	0,18	0,12
	СП	31	43	25,5	25,5	28,9	[illegible]1,9	[illegible]3,9	18,1	51,9	51,1	43,0	33,0
Белка BELKA	PQ	0,10	—	0,10	0,11	0,11	0,09	0,07	0,09	0,07	0,08	0,09	0,09
	QT	0,31	0,26	0,27	0,29	0,29	0,25	0,22	0,25	0,28	0,27	0,29	0,24
	P_1	—	—	0,1[illegible]	0,15	0,17	0,14	0,10	0,15	0,15	0,12	0,17	0,14
	R_1	—	—	0,4[illegible]	0,48	0,5[illegible]	0,41	0,24	0,51	0,48	0,41	0,40	0,47
	T_1	—	—	0,32	0,29	0,25	0,25	0,10	0,25	0,23	0,15	0,22	0,22
	СП	36	51	31,7	35,7	37,4	25,8	62,3	30,9	39,0	32,6	36,0	20,0
Пчелка PCHELKA	PQ	0,13	0,12	0,12	0,10	0,14	0,13	0,10	0,11	0,09	0,13	0,14	0,12
	QT	0,20	0,18	0,21	0,20	0,21	0,20	0,21	0,22	0,20	0,22	0,22	0,22
	P_1	—	0,15	0,16	0,36	0,22	0,17	0,40	0,24	0,1	0,1	0,1	0,2
	R_1	—	0,35	1,23	2,67	1,6	1,23	3,1	1,79	1,0	1,2	1,5	1,3
	T_1	—	0,33	0,18	0,44	0,27	0,32	0,7	0,34	—	—	—	—
	СП	27,7	26,5	31,0	29,0	26,0	23,5	27,6	27,0	27,6	24,0	22,0	25,5
Мушка MUSHKA	PQ	0,11	0,10	0,08	0,10	0,10	0,11	0,10	0,10	0,10	0,10	0,10	0,10
	QT	0,25	0,24	0,20	0,23	0,23	0,22	0,23	0,24	0,23	0,24	0,26	0,24
	P_1	—	0,13	0,10	0,10	0,11	0,12	0,10	0,10	0,10	0,10	0,10	0,10
	R_1	—	0,70	0,73	0,68	0,56	0,56	0,72	0,68	0,5	0,68	0,5	0,5
	T_1	—	0,35	0,47	0,32	0,28	0,27	0,34	0,38	—	—	—	—
	СП	23,8	47,6	36,9	44,9	40,2	39,0	35,6	27,8	38,0	34,0	30,5	36,0

Key. a. Name of dog.
b. EKG parameters.
c. Initial prestart data.
d. Weightlessness.
e. Earth orbits (helical).
f. 4 hours.
g. 5 minutes.
h. Strelka, Belka, Pchelka, Mushka.

TABLE 9. CHANGE IN SOME PHYSIOLOGICAL INDICES IN DOGS DURING WEIGHTLESSNESS FOR ABOUT 1 HOUR (PULSE RATE, BEATS/MIN; PQ AND QT INTERVALS, SECONDS; EKG AMPLITUDES IN APPROPRIATE UNITS; SYSTOLIC INDEX IN %) (AVERAGE FINDINGS)

a	b	c		d		
		e	f	g	h	i
j Чернушка	k Частота пульса	127	147	135	136	[illegible]
	PQ	0,06	0,10	0,10	0,08	[illegible]
	QT	0,24	0,18	0,18	0,21	[illegible]
	P_1	—	0,29	0,30	0,25	[illegible]
	R_1	—	0,90	1,33	1,15	1,01
	T_1	—	−0,37	−0,26	−0,26	[illegible]
	СИ	—	44,0	42,0	47,0	[illegible]
Звездочка	k Частота пульса	—	93,0	138	102,0	—
	PQ	0,06	0,10	0,09	0,10	—
	QT	0,26	0,22	0,19	0,23	—
	P_1	—	0,40	[illegible]	[illegible]	—
	R_1	—	1,90	1,78	1,83	—
	T_1	—	−0,38	[illegible]	−0,38	—
	СИ	—	34,0	43,0	[illegible]	—

Key: a. Name of dog.
b. Physiological indices.
c. Initial prestart values.
d. Weightlessness.
e. 4 hours.
f. 5 minutes.
g. First 5 minutes.
h. Second 5 minutes.
i. Last 5 minutes.
j. Chernushka, Zvezdochka.
k. Pulse rate.

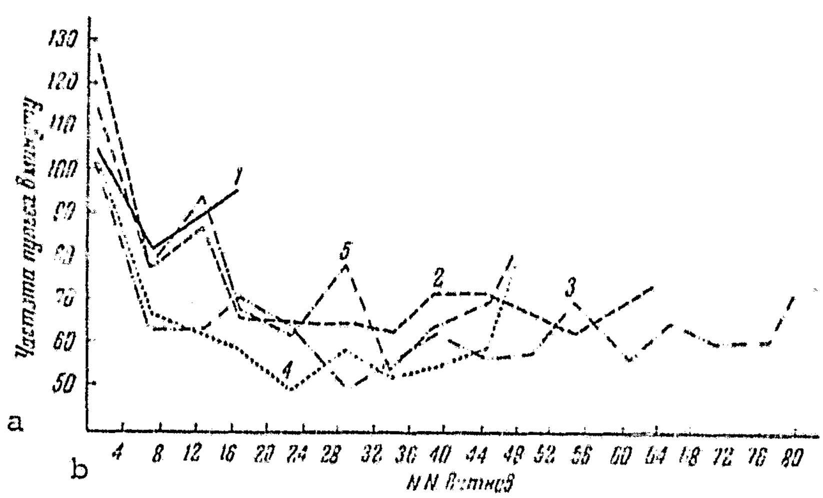

Fig. 2. Change in pulse rate of astronauts at individual stages of weightless flight: 1 - G. S. Titov; 2 - A. G. Nikolayev; 3 - V. F. Bykovskiy; 4 - P. R. Popovich; 5 - V. V. Tereshkova.

Key: a. Pulse rate (min).
b. Number of orbits.

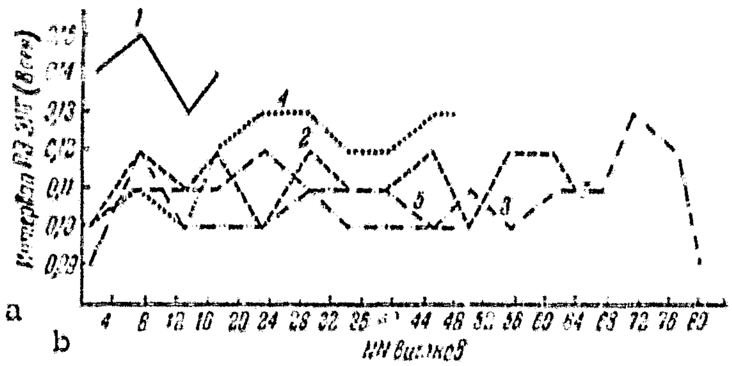

Fig. 3. Change in length of PQ interval in astronauts' EKG: 1 - G. S. Titov; 2 - A. G. Nikolayev; 3 - V. F. Bykovskiy; 4 - P. R. Popovich; 5 - V. V. Tereshkova
Key: a. PQ interval (sec).
b. Number of orbits.

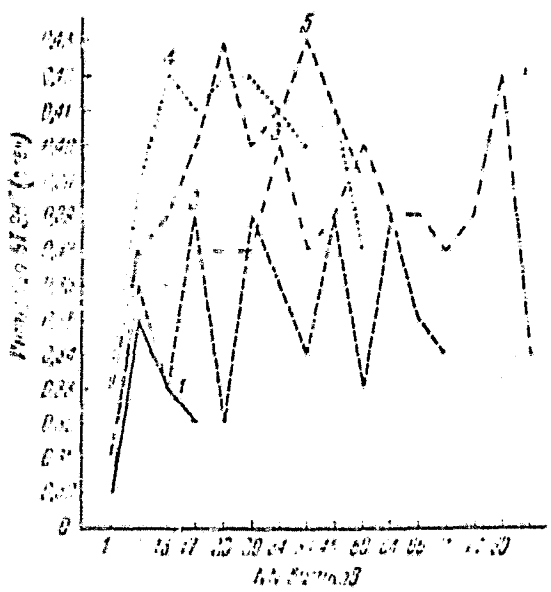

Fig. 4. Change in length of QT interval in astronauts' EKG: (rest as in Fig. 3)
Key: a. QT interval (sec).
b. Number of orbits.

Before and after suborbital flights a morphological study of the blood was made. Regularly, except for a single case, there is a rise in the count of leukocytes having rod nuclei (from 2 to 30%) and a drop in the lymphocyte count (Table 5). At present it is difficult to find a reason /356 for such a phenomenon. Apparently, it is conditioned by the animal's development of a stress reaction to a whole complex of factors and before all others to the effect of negative overload. I. I. Kas'yan et al. (1962) feel, that leukocytosis is the result of both stress and blood redistribution and most of all of entry into the blood by elements of the leuko- series from depositing organs. The authors cited, in experiments with 12 dogs, studied pre- and postflight red blood and observed no abnormal deviations in respect to red blood indices.

At the present time a good number of studies have been done in regard to the effect of shortterm weightlessness on humans. They were carried out when aircraft were making Keller parabola flights (Diringshofen, 1951, 1959; Beckh, 1953, 1954, 1956, 1958, 1959; Kas'yan, 1962, 1963a, b, c, etc.) and during rocket launchings (Augerson, Laughlin, 1961; Laughlin, Augerson, 1961, etc.).

Table 6 presents data on the dynamics of pulse rate and BP of persons observed in parabolic weightless flight. These persons may be divided into 3 groups on the

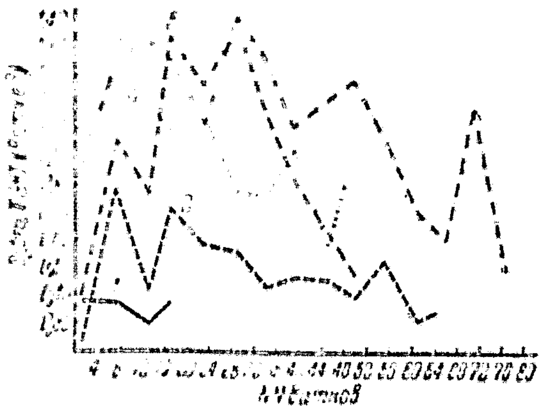

Fig. 5. Changes in T wave amplitude of astronauts' EKG: 1 - G. S. Titov; 2 - A. G. Nikolayev; 3 - V. F. Bykovskiy; P. R. Popovich; 5 - V. V. Tereshkova
Key: a. T wave (appropriate units)
b. Number of orbits.

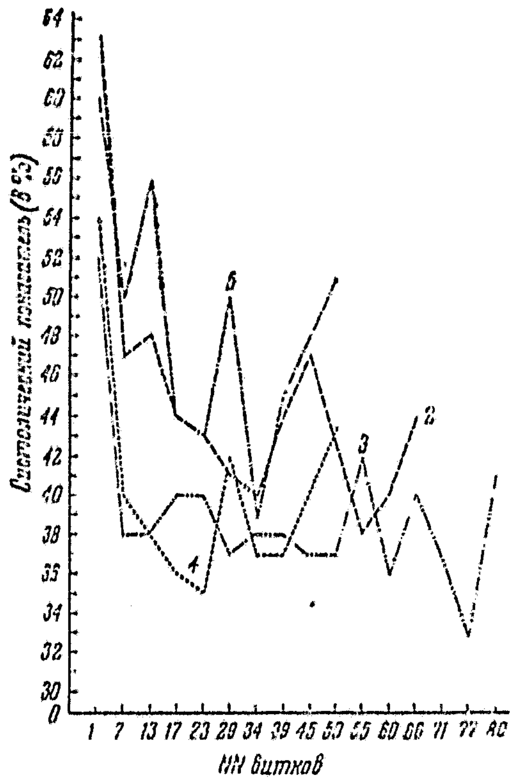

Fig. 6. Change in systolic index of astronauts: (rest as in Fig. 5)
Key: a. Systolic index (%)
b. Number of orbits.

basis of the direction taken by the changes under discussion: group I - indices lower, group II - indices higher, group III - no change. During horizontal flight most of the subjects showed a faster pulse, apparently an indication of neuroemotional tension. As an unusual factor weightlessness at first induced increased tension, but as time went on the tension diminished as the effect continued, so that there was a tendency to lower pulse rate and BP. In this context the pace at which functional normalization of the cardiovascular system occurred depended upon for the most part on the individual qualities of the organism (Kas'yan, 1963a, b,etc.).

Characteristic changes were discovered /358 when an analysis was made of the bioelectric phenomena occurring in the cardiac muscle. I. I. Kas'yan (1962) in experiments with 55 test subjects found, that in shortterm weightlessness, along with slower pulse, there was normalization of EKG elements. Voltage of the P_2, R_2 and T_2 waves approximated values recorded in horizontal flight; the PQ, QRS and QT intervals as well as the cardiac electric axis were within the limits permissible for physiological fluctuations. Fig. 1 gives specimens of the record of the indices for some physiological functions of the astronauts Yu. Gagarin and A. Nikolayev made during circumterrestrial parabolic flights.

The materials on shortterm weightlessness (up to 45 sec) as it affects the human organism permit the conclusion, that in such a case no real cardiovascular disorder

TABLE 10. BASIC PHYSIOLOGICAL MECHANISMS FOR THE EFFECT OF WEIGHTLESSNESS ON THE CARDIOVASCULAR SYSTEM

Effect	Change in the organism	Physiological mechanisms	Reaction of the organism
Immediate (hydrostatic BP lowered significantly)	BP drops, stasis in venous bed, venous flow difficult	Change in tone of parasympathetic and sympathetic nervous systems	Moderate drop in cardiac contraction rate, drop in BP
Mediated (disruption of coordinated work of analyzers taking part in regulation of body in space)	Disturbance of motor component of regulatory reflexes	Formation of new functional systematization in view of new relationships	Changes in autonomic component of regulatory reflexes, lability of autonomic indices

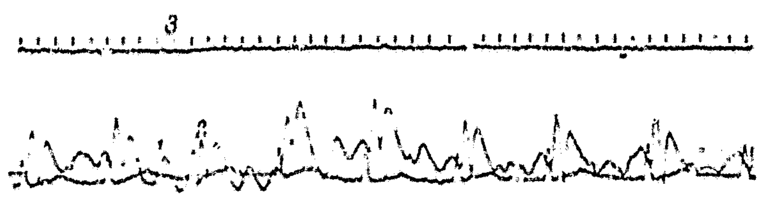

Fig. 7. Telemetric record of physiological indices for astronaut G. S. Titov during weightlessness: 1 - kinetocardiogram; 2 - EKG; 3 - time indicator

is induced. In these investigations data was also obtained on lowered BP, slower pulse and the lability of some autonomic indices during weightlessness. However, these data were inadequate for definitive conclusions on the condition of blood circulation during longterm weightlessness. Moreover, during parabolic flights in aircraft there was a gravitational effect (up to 3.5 units) before and after weightlessness, that made it extraordinarily difficult to anlayze the material obtained.

There was a need for special studies done on animals under conditions of protracted weightlessness and this became possible with the launching of artificial earth satellites.

As is well known, on 3 March 1957 the Soviet Union saw realized the first artificial earth satellite launched with the dog Layka on board. This first space experiment provided precious information of a scientific nature (Chernov, Yakovlev, 1958; Balakhovskiy et al., 1962). It was established, that in the prestart period indices of the cardiovascular system were within the normal range: Pulse 78-120/min, length of PQ and QT intervals respectively 0.12-0.20 and 0.18-0.26 sec. Once the satellite went into orbit the pulse at first was a bit high in comparison with data for entry of an aircraft into orbit but then began gradually to approach the initial value. It was reached, however, about three times as slowly as under earth conditions where the animals were subjected to the same amounts of gravitational pull. In weightlessness the range of the PQ interval was 0.09-0.12 sec and that of the QT was 0.21-0.25 sec. The shape and size of the T wave underwent rather significant changes: in the prestart period it was negative but during orbital flight it was positive. Such alterations in T wave amplitude seemed to derive from a change in the electric axis of the heart.

In subsequent launchings of satellite spacecraft with animals aboard a great amount of medico-biological information was gathered. Tables 7-9 present some of the data in respect to the physiological reactions of experimental animals.

Analysis of the materials shows, that there is a reciprocal correlation between change in the time parameters of the EKG and pulse rate. Where the pulse rate rises there is also a shortening of the PQ and QT intervals and vice versa. Practically all the animals during the time spent in weightlessness presented a pulse and EKG which at first was changed and then drew closer to the initial values; in some this happened rather quickly, in others slowly (Strelka and Pchelka experienced this already in the second earth orbit, Belka in the first, Mushka in the fourteenth). It /359
should be noted, that pulse lability (Table 7) in all experimental animals was maintained to the end of the weightless period. In Belka and Strelka there was a /360
significant pulse acceleration during earth orbits 7 and 13 (Table 7). V. V. Parin et al. (1962) explain this by periodic wavelike changes in sympathetic and parasympathetic influences conditioned by a change in afferentation. Increase in pulse rate in this case may be also connected with circadian rhythm. As we know, orbits 6 and 7 corresponded to the end of a single day and 13 and 14 to the beginning of another. The EKG amplitude parameters are extremely difficult to analyze (Tables 7-9). Out of 6 dogs one (Zvezdochka) showed an increase of P_1 amplitude in weightlessness, in 4 it went down and in one (Strelka) there was practically no change. The R_1 voltage rose for Chernushka and Pchelka, went down for Zvezdochka, Strelka, Mushka and remained the same for Pchelka and Belka. Even less definite was the direction taken by the amplitude of the T_1 wave. Increased in 2 dogs (Zvezdochka, Strelka), decreased in 2

(Chernushka and Belka), unchanged in Pchelka and Mushka. Such differences are explained in some degree by the individual characteristics of the higher regulatory mechanisms of the animals' autonomic functions and special features of telemetric recording. As we know, a discrete EKG record augments inaccuracy in the determination of amplitude indices, especially for the P and R wave and all the more so that the quality of the EKG record is often sacrificed due to the deposit of muscular biotics produced when the animals move.

During orbital flights recordings were made of the animals' BP and phonocardiograms were taken (Belka and Strelka). Analysis of the data obtained shows, that arterial pressure dropped, as a rule, during weightlessness, but there were periods when it rose (see Table 11). Thus, immediately before flight Strelka's BP was 140/51, during orbit 4 it was 96/34, in earth orbit 7 it was 181 and in orbit 14 it was 112 over 31. In weightlessness (Strelka) one noted weakening of the first and second /361 cardiac tones, although in the prestart examinations the phonogram was the ordinary one for the particular type of animal (Antipov et al., 1962).

The materials obtained during a long period of weightlessness made it possible to form a conclusion about the possibility of having human participation in the study. As we know, 10 persons have so far completed orbital space flights, 6 from the Soviet Union and 4 from the United States.

Figures 2-6 show the results for some indices of functional condition of the cardiovascular system during space experiments. In a previous published work we described the dynamics of changes in these indices (Yazdovskiy et al., 1964). Here we will make only a brief reference to the direction of these changes. Thus, pulse rate went down during weightlessness (Fig. 2) and equalled the initial value (data /362 from observation some days previous to start), and often sank below it. In almost all cases one noted a definite lability in this index. For short intervals (with no apparent cause) the pulse rate sank to 10-15/min or lower. This was particularly striking in astronauts G. S. Titov, P. R. Popovich and V. V. Tereshkova. Individual elements of the EKG differed variously: the QT interval was shortened at the beginning and end of the weightless period and went up slightly at its midpoint (Fig. 3), the PQ interval showed about the same change but was less distinct (Fig. 4), the amplitude of the T wave increased as the weightless period grew with a diminution at the beginning and end (Fig. 5). The systolic index dropped gradually (Fig. 6). The materials (Figures 2-6) indicate great fluctuations in the indices under study.

In the case of the astronauts G. S. Titov, V. F. Bykovskiy and V. V. Tereshkova there was also a study made of mechanical cardiac functioning (kinetocardiogram and seismocardiogram). It was ascertained, that they showed no real alteration (Sisakyan, Yazdovskiy, 1962), although there were some deviations: some increase in mechanical systole, reduction in amplitude indices, etc. Fig. 7 provides samples of a kinetographic record for astronaut G. S. Titov during weightlessness.

While the Soviet astronauts were in flight a great deal of very comprehensive scientific information was received in regard to the condition of blood circulation during longterm weightlessness. In many points there is agreement with the results of experiments conducted with animals (during both shortterm and longterm weightlessness) as well as with human subjects (during Keller parabola flights). The experimental materials make it possible to draw a conclusion about the fact, that human /363 blood circulation shows no disruption during 5 days' weightlessness; however there are some special features in the functioning of the cardiovascular system under such conditions: diminution in the cardiac contraction rate and BP level and at times a reduction in the figures recorded under earth conditions; great fluctuation of the indices referred to above; slow return of some indices to their initial level under weightless conditions following the active phase of the flight.

At the moment we still do not have a complete study of how weightlessness affects humans and animals physiologically. Thus, Stutman and Olson (1960) found, that in shortterm weightlessness during parabolic flights the BP goes down and so does the return of venous blood. Burch and Gerathewohl (1960) assess this phenomenon as the heart's functional adaptive response to decreased mechanical load. Graybiel et al. (1959) try to explain the pulse slowdown in monkeys during weightlessness in terms of the animals' fear, that may produce inhibition of cardiac contractions and dilatation of the vessels. One can hardly be in complete agreement, since this sort of reaction during weightlessness persists for a protracted period (hours, days) and, especially, is noted in both animals and humans.

There have been some findings on blood circulation changes in experiments with a prolonged stay of human subjects in an aqueous environment (Graveline et al., 1961; Graveline, 1962; Lawton, 1962, etc.).

It was discovered, that for test subjects under such conditions physical /364
loading was followed by a significant increase of cardiac contractions and a drop in pulse BP. In the EKG the P wave was augmented and the S and T merged. The authors explain the mechanism of the condition of orthostatic hypotension in terms of blood redistribution in the vascular bed and some changes in reflex reactions.

Experimental materials and literature data, in our opinion, support the thought, that there is immediate and mediated action exerted by weightlessness on blood circulation. By the immediate effect we understand the whole complex of reactions conditioned by a significant drop in hydrostatic BP. As a result there is a drop in blood pressure (arterial and venous), there is an accumulation of blood in the venous bed it would seem, venous flow from the upper portions of the body is impeded, etc. The latter situation may induce a relative rise of intracranial pressure and consequently heightening of the tone of the parasympathetic nervous system with all ensuing consequences: drop in pulse rate, BP, etc. Of course there is at the moment no reason for denying, that when the tone of the vagus nerve increases, that of the sympathetic goes down. Here there is a need for special investigations. Accumulation of blood in the venous bed in its turn likewise serves as a strong irritant of vascular receptors and in a reflex way inhibits cardiac action and elevates the tone of the vagus nerve.

Analysis of the experimental material obtained while astronauts were weightless indicates, that the pulse slows down and BP drops at times even below the level recorded on earth. However we have not been successful in establishing a definite dependence relationship between a reduction in the functioning of the cardiovascular system and the time spent in weightlessness. This seems to occur because the autonomic function in the organism is always maintained at the level effective for normal activity of the most important organs (nervous system, skeletal muscles, heart, kidneys, etc.); disturbances in blood circulation produced by a lowering of hydrostatic pressure are not significant (according to the findings of a number of authors the drop in BP for this reason does not exceed 10-15%) and in addition an important role is played by neuroemotional excitation since, as we know, when there is excitement the tone of the vagus nerve goes down and consequently BP rises and so does pulse rate.

When we speak of the mediated effect of weightlessness on blood circulation we are talking about the entire complex of cardiovascular reactions that arise as a result of disturbance to the functional systematization of analyzers (proprioceptive, cutaneomechanical, interoceptive, visual, vestibular) that help to analyze space relationships and the attitude of the body in space (Komendantov, 1959, et al.). We know that bodily equilibrium is achieved through attitudinal reflexes, the oldest of all reflex reactions, that oppose the gravity pull of the earth (Komendantov, 1963, et al.). In the weightless state the flow of the attitudinal reflexes is altered (Yazdovskiy et al., 1960), since there is a substantial change in afferentation from all mechanoreceptors. A change in attitudinal reflexes inevitably affects the autonomic component and before all the function of blood circulation. We begin to understand the significant fluctuations in autonomic indices (pulse etc.). The question arises /365 about the importance of weightless effect mechanisms on the organism, whether immediately or mediately. It appears, that when a person finds himself bound to this situation, the immediate mechanism is the determining one. In a non-fixed or "free floating" situation the mediate would seem to dominate, since here the changes in the motor component of attitudinal reflexes are more pronounced and there is a corresponding change in the autonomic component.

Table 10 presents suggested physiological mechanisms for the effect of weightlessness on the cardiovascular system. In weightlessness changes (disturbances) arise due to a significant drop in the hydrostatic pressure of the blood and disruption of the coordination work of the analyzers. It would seem that in the genesis of disturbances an important role is played by the exclusion of the vestibular analyzer. Thus, according to the findings of Bek (1953, 1954), Schock (1961), Ye. M. Yuganov (1963), G. I. Pavlov (1963) and others, the reactions of delabyrinthed animals in weightlessness are less pronounced. The same opinion is held by G. L. Komendantov and V. I. Kopanev (1962). They feel, that orientation in earth space is done chiefly by the visual and vestibular analyzers, whereas in weightlessness it is mostly the visual.

As has already been indicated, in proportion to one's stay in weightlessness a certain adaptation to unusual conditions develops. Obviously the physiological base for this adaptation is the formation of a new systematization in the work of the analyzers taking part in the analysis of space relationships and in the attitude of the body in space. In this case following such formation there is a reinforcement of the autonomic component at a level suited to meet the new conditions. Nevertheless we must keep in mind, that the new systematization is impermanent and we cannot exclude the possibility that it may be disrupted due to adverse factors: fatigue, temperature, etc. This must be counted on in organizing work and rest periods for persons staying weightless a long time.

We can scarcely expect, that in longterm weightlessness the disturbances referred to will develop. However they may appear in persons already adapted to weightlessness once they have returned to earth and are subjected to acceleration. /366

We already have experimental data (Bek, 1958, 1959; Kas'yan, Kopanev, 1963, et al.) indicating that in longterm weightlessness adaptation may not occur but rather that vestibular-autonomic phenomena are reinforced. We know that on earth 3-5 percent of human test subjects do not adapt to vibration. It seems that something similar may take place in space flight. Thus the need for continuous refinement of methods of selecting astronauts and training them as well as the development of preventive measures directed at heightening the resistance of the organism to the adverse effect of prolonged weightlessness. In this context an interesting proposal has been made by Gerathewohl and Ward (1960) in regard to venous stasis prophylaxis. They think that bodily attitudes should be adopted that provide moderate pinching of the calf muscles. In our opinion it would also be useful to provide a costume with a vibrator for the upper and lower extremities. When turned on periodically it would increase general muscle tone and the blood would be moved along toward the heart.

The extraordinary slowness of the return to initial values of the pulse in animals and humans during weightlessness has evoked on the part of some researchers an attempted explanation in terms of the contrast effect when the organism passes from one state to another (Chernov, Yakovlev, 1958; Gerathewohl, Ward, 1960, et al.). We believe, that in addition the slow adaptation of the cardiovascular system is conditioned by the formation of a new functional systematization of the analyzers taking part in the body's attitude in space and likewise by hormonal shifts. As we know, launching of the spacecraft, gravitational pull and weightlessness are strong biostimulants. In this case the blood receives a large number of hormonal substances that seem to have a significant effect and prevent rapid return of some indices to their initial values.

Conclusions

1. When humans and animals engaged in flights into proximal space in rocket-propelled aircraft they presented no substantial disturbances in the system of blood circulation.

2. In shortterm and longterm (up to 120 hours) weightlessness one may divide all test subjects into three groups on the basis of the type and degree of autonomic reactions (pulse rate and arterial pressure): a) showing clear reduction in pulse rate and arterial pressure , at times even below values recorded under earth conditions; b) showing a slight increase in pulse rate and an insignificant rise in arterial pressure; c) showing no noticeable changes in these indices.

3. The drop in pulse rate and arterial pressure, increased lability of some autonomic indices and retarded normalization in indices of the functional condition of the cardiovascular system are explained by a significant reduction in the hydrostatic pressure of the blood (direct effect of weightlessness) and disruption of the functional systematization of the analyzers (indirect effect of weightlessness).

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