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LABORATORY SIMULATION OF THE ACTION OF
WEIGHTLESSNESS ON THE HUMAN ORGANISM

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16. Abstract This report is about how scientists in the U.S. and Russia have been trying to simulate weightlessness in the laboratory. They have tested animals in rockets and have used satellites. There are many different methods for laboratory modeling of weightlessness. This report gives a good summary of these methods and it tells that during the study of weightlessness, when they ran into unfavorable effects, how they continued to experiment. Enclosed within this report are explicit diagrams that describe the lab models for testing weightlessness.			
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LABORATORY SIMULATION OF THE EFFECT OF WEIGHTLESSNESS
ON THE HUMAN ORGANISM

Attempts at simulating the effects of weightlessness in the /1.
laboratory have been made by scientists in the USSR and the United
States since the first days of space biology and medicine. The
moment the development of rocket technology created the prerequisites
accomplishing ~~manned~~ spaceflight, search for methods of predicting
man's health under conditions of weightlessness began. Along with
the development of speculative concepts on the possible mechanisms
and consequences of the effects of weightlessness on man, very intense
efforts were begun to solve experimentally this problem. The specialists
were initially attracted by the possibility of testing the effect of
weightlessness on animals, for which rocket and artificial earth
satellite launchings were used. Weightlessness was a real factor
in these experiments, however, the adequacy of simulation of man by
laboratory animals caused some well-founded doubts. Therefore,
attempts were made at laboratory simulation of the effects of weight-
lessness on actual persons in parallel with the tests on animals.

In the literature at the end of the 50's and 60's, different
methods for laboratory simulation of the effects of weightlessness
were widely discussed. The appropriate experimental research was conducted.
The first successful manned space flights gave space medicine specialists
a new, very effective instrument - the possibility of studying the
actual effect of weightlessness on an actual person, which relegated
both animal research and human simulation experiments to the back-

ground. The idea for gradual progress of increasing the duration of /2.
space flights became prevalent. And in spite of the fact that research
conducted during the flights confirmed sufficiently well the predictions
made earlier on the basis of simulation experiments and certain analogies,
the empirical approach began to dominate. The main efforts of the space
medicine specialists were concentrated on studying the cosmonauts,
and simulation experiments were conducted by only a few physiological
laboratories.

Renewed interest in simulation experiments was linked to
preparation for long-term space flights (3,8,9,10) and with the
development, in association with preparation, of prophylactic measures
for the unfavorable effects of weightlessness. At the IV international
symposium "Man in Space" in 1971, pertinent reports (5) were given
and a special discussion was conducted on simulating the physiological
effects of weightlessness. Participants in the discussions,
E. Wood, C. Berry and others (16), expressed a number of doubts on
the adequacy of these surface models, and this critical opinion was
dominant.

Nevertheless, research on the simulation experiments was
continued both in the USA and the USSR as applicable to different aspects
of the medical safety of space flights. The questions of simulating the
effect of weightlessness on man has been examined since 1973 (11)
by a joint American-Soviet work group on space biology and medicine.

The most convenient and available model for physiological research
was the bed regimen with its different modifications. As a result,
the bed regimen has been the most widely used in recent years.

However, we should not forget about the possible use of other models which can be used effectively to solve specific problems either in conjunction with the bed regimen or in lieu of it.

/3.

Table 1 shows a very arbitrary outline of the primary effects of weightlessness on the human organism and the possible models more or less completely reproducing these effects. The outline does not take into account the possibility of the immediate effect of weightlessness on the distribution of the intracellular structures, the metabolism and cell division, because neither contemporary theoretical concepts, nor special biological experiments confirm the reality of such an effect (in any case as applied to cells of organisms that do not have a strict gravitational orientation).

The central place in the outline is occupied by such effects of weightlessness as the redistribution of blood manifested in the increase of filling of the vessels of the chest cavity and the head with blood, by liquidation of the "gravitational depots" and a decrease of the extra-cellular liquid in the lower extremities, as well as hypodynamia which is connected with the removal of the gravitational load from the osteal support apparatus and muscular system. All contemporary thoughts on the pathogenesis of the effects of weightlessness are based mainly on these two primary effects, which are purportedly responsible for the development of the complex pathogenetic chain of events which include disturbance of the water-salt exchange, change in the hormonal system's activity, disturbance of the neurohumoral regulation, muscle atrophy, etc. At the same time, these effects are simulated quite well by different types of modeling. As we

already mentioned, the most widely used models are those with the subject in a horizontal position with a strict bed regimen. A great deal of material has been at the present time compiled on the human physiological reactions to prolonged stays on a bed regimen. A /4. summary of similar research was given by Dr. Sandler in his report presented at the previous meeting of the American-Soviet working group. An experiment was conducted in the Soviet Union in 1971 during which 9 subjects underwent a bed regimen in an antiorthostatic position at an angle of -4° for a period of 30 days (4). Subsequently, the antiorthostatic position became one of the standard methods, with the aid of which, in our country, the effects of weightlessness were simulated. A detailed comparison of these two variations of the bed regimen is the main topic of the reports and discussions at this conference.

The closeness of the human organism's reaction to the bed regimen and the actual effect of weightlessness are obvious which is demonstrated rather well by several end effects, such as decalcination of the bone tissue, a decrease in the volume of blood circulated, muscular atrophy, a decrease in the orthostatic stability, etc. However, the equivalence of the end effects still is not evidence of the identity of the primary mechanisms of the action, and at the same time even a priori comparison of the model with the original points out its shortcomings. In our opinion, the general shortcomings of all variations of the bed regimen are as follows:

- impossibility of reproducing the equalizations of the hydrostatic pressure inherent to weightlessness in small circle vessels. Insofar as the pressure in the pulmonary artery is commensurate with

hydrostatic pressure of the blood column, no matter what man's position is relative to the vector of the force of gravity, the postural action on the perfusion of the pulmonary alveolae is very significant.

When man is in a vertical position, the perfusion of the apical lobes of the lung is twice as small as that of the basal ones. In a horizontal position, the apico-basal gradient disappears, but the ventral-dorsal gradient occurs. The ventral alveolae are perfused 1.7 times less than the dorsal. In a horizontal position on the side an analogous difference occurs between the left and the right lungs (7). At the same time, one can assume that weightlessness (at any rate during the initial stages of the flight) causes equal perfusion in the lungs with a general increase of their filling with blood. This difference may be reflected in several secondary reactions, including the value of the physiological (alveolar) by-pass; /5.

- the impossibility of more or less complete reproduction of the subjective feeling of weightlessness. This circumstance is connected with maintaining support, the necessity to overcome weight during movements and the maintenance of the constant action of the otoliths on the otolithic membrane. It is highly possible that the afferent activity differing from weightlessness causes some difference in the autonomic reactions. At any rate, the vestibular-autonomic disorders as a rule do not occur during the bed regimen;

- incomplete reproduction of blood redistribution which is inherent to weightlessness. In a horizontal position man's hydrostatic pressure of the blood and tissue liquids is significantly decreased (by 5-6 times in comparison with the vertical position), but it does not disappear

completely. At the same time, the area of support significantly increases and the total volume of the vascular bed can grow, extended by hydrostatic pressure. Thus the peripheral "hydrostatic depot" does not disappear completely, it is only decreased, therefore, the volume of central blood cannot increase sufficiently for weightlessness.

This last deficiency can be significantly decreased by placing the body head downwards, and from this point of view the antiorthostatic model seems more preferable to us. Information by Soviet specialists that /6. was published in periodicals and presented at the meeting in Erevan and at this conference confirm our suggestions. Analogous research was conducted by Americans, particularly by Bolitser et al. (22), who found a greater similarity of changes in the water-salt exchange resulting from the effect of weightlessness and antiorthostatic position than from the horizontal position.

The immersion model is quite adequate, however, even in this model as in the bed regimen model, the removal of the hydrostatic pressure gradient in the small circle vessels and the removal of the constant action of the otoliths on the sensing apparatus of the otolithic membrane are not reproduced. However, in all other aspects the immersion model more closely approximates weightlessness than the bed regimen model. This relates to the degree of redistribution of blood, the elimination of support and the removal of the weight load from the body and its segments.

The use of water immersion to simulate the physiological effects of weightlessness began in the USA and the USSR at the end of the 50's-beginning of the 60's in research by Graveline (18,19),

Demidov et al. (6,12). Moreover, this model became the base in physiological research on regulating the water-salt exchange and the volume of circulating blood during hypervolemia, and in recent years, in research on small circle hemodynamics and external respiration. Water immersion was also used in training cosmonauts to cope with work and to move in conditions of weightlessness, and also in developing means and methods of stabilizing man and his body segments during work operations in a space flight. Nevertheless, the number of works published recently on using immersion for simulating weightlessness has significantly decreased. This is apparently explained by the methodical difficulties /7. in conducting immersion experiments - maceration of the skin resulting from prolonged contact with water, the necessity of precise thermal regulation, the complexity of carrying out hygienic procedures. Many of these difficulties have been satisfactorily overcome by using waterproof elastic membranes covering the water surface. A similar methodical technique, developed by Ye. B. Shulizhenko (13,15), permitted several series of experiments of varying lengths, right up to 56 days. There were no side effects occurring as a result of this long experimentation. We should note that several of the subjects who had their eyes closed during immersion experienced complete disorientation, sometimes they experienced dizziness. The subjects often complained of muscular pain in the area of the loins. They felt better in 5-7 days, as a rule.

As far as the hemodynamic and the water-salt exchange factor were concerned, they coincide with those of the bed regimen research, however, dehydration and decreased blood circulation volume occur more quickly even during the first 6-8 hours of immersion. The orthostatic

stability and endurance of the head-pelvis load (14) significantly worsen. The excretion of water and mineral substances varies in a wide range and the negative water balance reaches 400-2000 ml by the 13th day. One gets the impression that the greatest differences between the bed regimen and the water immersion models, as well as between the horizontal position and orthostasis, take place during the first 3-5 days of the experiment. Then, these differences gradually disappear.

Suspending the subject in a horizontal position is also a very interesting model. It was widely used in the USA and the USSR in researching biomechanics of man's movement during a decreased gravity situation (2), however, this model has not been used in long term experiments on man. The use of a similar model on monkeys (1) indicates its prospective use in experiments on humans. The advantage of such a model in comparison with the bed regimen is the possibility of the relative freedom of movement and the creation of hypodynamia without hypokinesia. /8.

As we already mentioned, the basic shortcoming of the listed models is the impossibility of reproducing reactions to weightlessness on the part of the vestibular apparatus and the pulmonary circulation. At the present time, the simulation of these effects is very complicated, and one of the only possible models is apparently the clinostat. At the beginning of the 60's several American researchers advanced the idea to combine the clinostat with the water immersion model (2). Calculation of the rate of rotation of the human body around the longitudinal axis, in a horizontal position, proceeded on the viscosity of the endolymph and the otoliths. It was shown that a rate of rotation of 30 revolutions per minute should insure a position of the otoliths

relative to the otolithic membrane the same as in weightlessness. This speed is apparently sufficient to liquidate physiologically the significant perfusion gradient of the pulmonary, because the blood movement through the small circle is approximately 10 seconds under a pressure which slightly exceeds the hydrostatic pressure. Moreover, if the variations in the filling of the lung vessels with blood are significant, it will be hardly reflected in the gas exchange, because there are several variations for each respiratory cycle. The centrifugal force occurring during the rotation is not great and is compensated for /9. in cases where the clinostat and water immersion models are combined.

This model is very attractive from the point of view of complete reproduction of the initial (physical) effects of weightlessness. However, its shortcomings are obvious: the complexity of creating a system safe for man, the necessity of maintaining practically complete immobility of the subject in order to avoid the occurrence of processional acceleration and Coriolis acceleration. It is also difficult to imagine long term experimentation in this situation over a period of a few hours or even a few days.

Apparently, these shortcomings lead to the fact that the clinostat model is not widely used. We have not found any publications on the results of research on the clinostat model. At the same time, this model is quite interesting for laboratory reproduction of the complex physiological changes that are characteristic of the initial stages of man under weightlessness.

In addition to the general models already examined that reproduce two or more of the initial physical effects of weightlessness, several partial models may be significant that reproduce only one

isolated effect. This could be very useful in establishing the significance of this one effect as it relates to the total complex of physiological changes that occur during weightlessness.

The use of a sectioned G-suit for simulating redistribution of blood characteristic during weightlessness seems very prospective to us. Constant many day wearing of the G-suit (the pressure in the ring seals may be reduced during sleep) while maintaining usual muscular activity can refine the significance of the hydrostatic factor in /10. the development of the orthostatic hypotonia and other disorders inherent to weightlessness. In addition, this method can be useful for simulating weightlessness in complex experiments and tests in ground models of spacecraft. The significance of hypodynamia can be researched during the corresponding standing or sitting fixation of the subject's body when the hydrostatic pressure of the blood and the tissue liquids are maximal. The fixation of the front wall of the abdominal cavity with special bandages can facilitate the explanation of the significance of gravitational deformation of the internal organs.

All of the aforementioned models reproduce the initial, essentially physical manifestations of weightlessness and, therefore, are most pathogenetic, since after the initial effects one can expect the development of a whole chain of secondary and intermediary reactions. However, there are other possible physiological methods of simulating human reactions to weightlessness. One of these methods is presently examining the transfer from prolonged acting overloads to normal gravitation. A priori such an approach can seem quite valuable, if we assume man's complete adaptation to hypergravitation and we find the

the quantitative equivalents of the transfer from hypergravitation to 1 gram and from 1 gram of weightlessness. However, the methodical approaches to conducting such research are quite difficult. Moreover, there is as yet no proof of the adequacy of such a model.

For primary (selective) testing of different means and methods of eliminating the unfavorable effects of weightlessness, the symptomatic models may be useful, which reproduce the final links in the orthogenetic chain by using the most technically expedient methods. Thus, /11. for example, the primary tests of effectiveness of different modified G-suits should be tested on persons with weak orthostatic stability, no matter what the cause of it is. This relates to means and methods of restoring muscular atrophy, prophylaxis and treatment of vestibular-autonomic disorders.

One of the methods of symptomatic simulation, which is particularly interesting, is presented on the outline. This is the prolonged stay of a subject in a revolving room. The symptomatology of the sensor, autonomic and the motor disorders, which occur at the speed of 4-6 revolutions per minute, closely resemble the symptoms of the first stage of weightlessness in man. The times of development of the adaptation process are also very close, as are the times for readaptation to normal conditions. We believe that this model could be very useful in developing methods for reducing and preventing vestibular-autonomic disorders and also for studying general regularities of the subject's adaptation to the physical factors, and for finding ways to speed up the adaptation process.

Table 2 presents possible methods of simulating the effects of weight-

lessness on the human organism as applied to one or another problem in space medicine. The adequacy of the model for each particular area is noted by a + or a - sign. The table is very theoretical in nature, because there is no experimental material to accomplish it reliably. Perhaps, the basic, if not the only significance of the table is to demonstrate the variety of possible methodical approaches to simulating different physiological effects of weightlessness, each of which is appropriate for use depending on the pertinent medical problem to be solved which confront the experimenter.

TABLE 1

WEIGHTLESSNESS			
removal of pressure of otoliths on the otolithic membrane	removal of hydrostatic pressure of the blood and tissue liquids	Unloading of support skeleton and antigravitational musculature	Removal of gravitational deformation of the body, organs and tissues
	creation of a balanced hydrostatic pressure in the branches of the pulmonary artery	increase of the volume of central blood. Elimination of "hydrostatic depot"	
		Limited movement. Fixation of the body or its segments	Fixation of the front wall of the abdominal cavity with a bandage
		G-suit. Introduction of blood substitute, physiological solution, etc.	
		Bed regimen: a) horizontal position, b) antiothostatic position Suspension of the body in a horizontal position	
		WATER IMMERSION	
Clinostat.	Clinostat + water immersion		
Transfer from increased artificial gravitation (many-day rotation on a centrifuge)			
	+G _z ~ 2-3 to normal conditions		
	Many-day stay in a revolving room		

TABLE 2

Problems of Simulation	Studying the phenomenon. (prognos.)				Testing the effectiveness of means for prophylaxis						
	acute period	length of effect	study of motor sphere	vestibule auton. disorders	orthostatic collapse	physical waving capability	atrophy of muscle and skeleton	metab. disorder	complex testing of prophylaxis measures	selection of crew members	training flight crew before flight
Moial Horizontal position	+	++	-	-	++	++	++	++	+	-	-
Antiorthostatic position	++	++	-	-	++	++	++	++	+	+	+
Water immersion (including "dry immersion")	++	++	++	-	++	++	++	++	+	+	++
G-suit, or negative pressure on the upper part of the body	+	?	-	-	++	++	-	?	++	-	++
Clinostat + water immersion (Muller barrel)	++	?	-	++	++	?	?	?	-	-	-
Suspension	+	++	++	?	++	++	++	++	+	-	+
Hypokinesia and hypodynamia (local and general)	-	+	-	-	+	++	++	+	+	-	-
Life in a revolving room + hypodynamia	++	++	?	+++	+	++	++	+	+++	+	-

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