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HAZARDS OF HIGH ALTITUDE DECOMPRESSION SICKNESS DURING FALLS IN BAROMETRIC PRESSURE FROM 1 ATM TO A FRACTION THEREOF

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Translation of "Opasnost Poyavleniya Vysotnykh Dekompressionnykh Rasstroystv (VDR) pri Perepadakh Barometricheskogo Davleniya ot 1 ATM do yeye Doley," Institute of Medical and Biological Problems, Ministry of Health USSR, Moscow (Paper delivered at the 10th Conference of Joint Soviet-American Working Group on Space Biology and Medicine, Houston, Texas, October 1979), 1979, pp 1-12

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16. Abstract

The article describes various tests related to studies concerning the effects of decompression sicknesses at varying pressure levels and physical activity. These tests indicate that there is no guarantee of freedom from decompression sicknesses when man transitions from a normally oxygenated normobaric nitrogen-oxygen atmosphere into an environment having a 0.4 atm or lower pressure and he is performing physical work.

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The choice of an artificial cabin atmosphere for space ships has been widely discussed by specialists from the USSR and USA during all stages of the development of space exploration. In the USSR the choice fell upon a normobaric oxygen-nitrogen atmosphere with a ratio of gases approximating that of air. Arguments in favor of this decision are: /1*

--relative fire safety,
--indisputable physiological adequacy,
--high volumetric specific heat of the gaseous milieu,
--the possibility of using a wider assortment of materials and assemblies for on-board systems.

A normobaric environment has obvious shortcomings, the primary one being the need for maintaining a relatively high pressure in space suits or allowing for an extended nitrogen desaturization period. The increased duration of space flights and the prospects for their broader expansion increase the importance of the positive features of a normobaric atmosphere. This circumstance, however, necessitates even greater attention to its shortcomings, since extra-vehicular operations and human work in open space may evolve from rare occurrences into daily, widespread activities.

This requires using reliable measures to ensure a safe working environment for a man in a space suit while providing maximum comfort, including a high degree of mobility for all of the suit's articulations. The lower the /2
excess pressure in the suit, the simpler it is to achieve the latter, although low pressure, in turn, carries with it the hazard of decompression sickness.

Aviation-related incidents of decompression sickness during drops in atmospheric pressure from 1 atm. to a fraction thereof have been studied by many researchers and laboratories around the world. The notion that there is a precise boundary marking a dangerous drop in pressure, before reaching which freedom from decompression sickness may be ensured, has long predominated. The concept of such a borderline was formulated on the basis of the

* Numbers in margin indicate pagination in original foreign text

ideas of D. Holden. A pressure of 270 mm Hg (or a pressure altitude of 8000 m.) was the generally accepted limit used in aviation. Cases of decompression sickness at higher pressures (lower altitudes) arose periodically. These were rare episodes, however, and, although quite serious incidents of decompression sickness have been described in great detail, virtually no attention has been directed to the possibility of high-altitude decompression sickness (HDS) occurring at altitudes below 8000 m. These ideas were not shaken by the classic research done by Harvey et al., which showed that in principle there are no danger limits for pressure drops, and that the likelihood of decompression sicknesses occurring was determined by a number of ancillary factors, such as, for example, physical stress, duration of exposure, etc.

In this connection, there are essential differences between incidents of decompression sickness in aviation, where the physical activity of the crew members is extremely limited and exposure time is small, and in space travel, where extra-vehicular activity requires the performance of intensive physical work over a long period of time. These differences have made it /3
necessary to conduct special experimental studies in altitude chambers, with the subjects "ascending" to various artificial altitudes and performing physical work after decompression.

Numerous researchers in the Soviet Union have so far amassed a considerable amount of material, which could be divided roughly into two parts. The first part consists of research done with the participation of volunteers and specifically directed at discovering the effects of decompression sicknesses at varying pressure levels and involving varying types of physical activity. Pressure suits were not used in these experiments, as a rule.

The second part consists of observations made on persons testing pressure suit systems under differing conditions. These subjects were not concerned with detecting the symptoms of decompression sickness but were oriented towards accomplishing a task. So the goal of the subjects in this group, moreso than the first group, was approximately that of cosmonauts. This is a rather important consideration, since the complaints of these subjects were practically the only criteria for detecting decompression sickness.

We tried to generalise the results of the first part of the experiments, done by Gramenitsky, Katuntsev, and Poleshchuk according to the initial protocols. This research has been published in part (1, 2, 3, 4). The experiments were done with the participation of clinically healthy young men aged 19 to 42 years, from various different professions: students, laboratory assistants, technicians, etc,

After a medical examination, the subjects went over to an altitude chamber /4 and donned oxygen masks. In all the experiments, the rate of ascent from ground level to 3000 m. was 10 m/sec, from 3000 m. to 5000 m. -- 15 m/sec, and from 5000 m. on -- 25 m/sec. Duration of the stay at altitude was to total 4-6 hours. During their stays at decreased pressure, the subjects in all the experimental variations performed a standardised amount of physical work, which included the following: while seated, the subject stretched out both arms and raised 4 kg dumbbells 20 times in one minute, then climbed a 30 cm step 20 times a minute for 3 minutes (60 times in all), and then once again raised the dumbbells for 1 minute. In accordance with prior instructions, the subjects periodically changed the "working leg" while climbing the step. One cycle of physical activity lasted 5 minutes. The work cycle was repeated, after 15 minute rest periods, over the entire course of the stay at altitude. Thus, three cycles of physical activity took place in each hour. Energy expenditure for the given amount of work totaled 174 $\pm$ 8.6 kcal/hour. In the period of work performance, the expenditure came to 5.6 $\pm$ 0.3 kcal/min.

If HDS occurred, the subjects informed the experimenters. The decision to continue or halt the experiment depended upon the nature and degree of illness. Repeated "ascents" were conducted no sooner than a week after the preceding one.

A table summarizing the results of the experiments is printed below.

Special notice should be made of the unexpectedly high percentage of /5 decompression sicknesses occurring at pressures of 0.4 (48%) and even 0.43 atm. and the low effectiveness of desaturization.

In addition, it should be pointed out that there was not a single case of severe decompression sickness in any of the experimental series. The predominant symptoms were pains in joints (94%), most frequently localized in the knees (60.5%), and rarely in the shoulders (12.8%) and ankles (9.6%).

The joint pains were frequently accompanied by dermal pruritus, and substernal pain and coughing sometimes appeared. The symptoms of HDS, as a rule, disappeared following descent to ground level, and in only three cases did a small amount of edema and tenderness upon movement of the joint remain over 2 or 3 days.

We should also note the tendency of the latent period of decompression sickness manifestation to decrease when the exposure "altitude" was increased.

Decompression sickness became more serious when the final pressure was decreased. Thus, at 0.35 atm.,.in 17.8% of the HDS cases the subjects could continue to complete the program, while 41% of the cases required rapid recompression. At the same time, when the final pressure was 0.4 atm., 29% of the persons with HDS completed the research program, while in only 17% of the cases was rapid recompression necessary.

Therefore, the data from this series of experiments has shown that pressure changes from 1 atm. to 0.40 and even 0.43 atm. did not provide freedom from decompression sicknesses where a human was performing physical work.

These data contradict the work of Vakar, Mazyn, et al. (5). These authors conducted 483 studies on 70 subjects. The ages and professions of the sub- /8
jects were analogous to those in the preceding series. The general plan of the experiments was the same as in the studies by Gramenitsky et al., but the physical stress was considerably higher: average hourly work expenditure was 400--450 kcal; the subjects raised a 15 kg weight to 70 cm and climbed a 35 cm step; 30 exercises per minute were done for 40 minutes, and they were begun again after 20 minutes of rest.

Despite the fact that the intensity of physical exercise was materially greater in the experiments of Vakar et al. than in Gramenitsky's, there were far fewer cases of decompression sickness.

Nº	Final Press mm Hg, atms	Desat'n time	Nº exprts./ Nº subjects	Nº of HDS/ Nº sbj experiencing	Nº of HDS cases in given exposure time, in hrs. 0-1	1-2	2-3	3-4	4-5	5-6	Nº of pers. with HDS completing progr.	Nº of pers. stopping expermnt w/in 15 min of HDS
1.	354 mm Hg 0.47 atm (6000m)	-	17/14	-	-	-	-	-	-	-	-	-
2.	330 mm Hg 0.43 atm (6500 m.)	-	31/19	10/7	1	2	3	1	3	-	3	2
3.	308 mm Hg 0.40 atm (7000 m.)	-	173/66	83/43	15	28	23	15	-	2	24	14
4.	263 mm Hg 0.35 atm (8100 m.)	-	138/76	73/42	23	29	9	9	3	-	13	30
5.	308 mm Hg 0.40 atm (7000 m.)	20 min	12/11	7/6	2	2	1	2	-	-	2	-
6.	308 mm Hg 0.40 atm (7000 m.)	60 min	21/8	6/5	3	-	3	-	-	-	-	3
7.	263 mm Hg 0.36 atm (8100 m.)	20 min	2/14	14/13	6	5	3	-	-	-	-	7
8.	263 mm Hg 0.35 atm (8100 m.)	40 min	8/8	5/5	1	3	1	-	-	-	-	2

Table 1. Results of Altitude Chamber Experiments not Using Pressure Suits.

Thus, at a final pressure of 0.4 atm. only 2 cases of decompression sickness were observed out of 434 experiments (0.46%), while with a final pressure of 0.35 atm. there were 8 cases out of 49 (16.3%). Both cases of HDS at 0.4 atm. manifested themselves as slight joint pains, while the HDS symptoms arising at 0.35 atm. were considerably more acute. We should note, however, that in the control series of studies, in which Vakar et al. used the standard physical stress, as applied by Gramenitsky, the results obtained were close to those of the first series of studies,

The second part of this work, as we have already remarked, was conducted during tests of pressure suits and systems at an absolute pressure of from 0.21 to 0.41 atm. (160--310 mm Hg). These experiments were carried out using differing goals and methodologies. The nature and intensiveness of the physical exercises differed considerably in the various tests. This circumstance obliged Barer, Golovkin, et al., in trying to generalize the /9
material from the observations (6), to break them up into several series and groups. The basic conditions of the experiments and their results are presented in table 2. As can be seen from the table, cases of HDS were extremely rare. Without prior desaturization, they are absent at pressures of 0.38--0.41 atm. True, we must make note of the comparatively short exposure to this pressure, the small quantity of observations, and the comparatively light physical stress.

Symptoms of HDS were also not observed at pressures of 0.36--0.38 atm. after prior nitrogen desaturization. HDS of slight or medium severity was observed in 6--12% of cases at pressures of 0.21--0.26 atm. after 1 hour's nitrogen desaturization.

Under these conditions, as well as the previous ones, there were no cases of serious decompression sickness requiring special treatment. In all cases the HDS were over after a return to normal barometric pressure. They consisted of muscle and joint pain accompanied in some cases by pruritus of the skin, As in the previous series, the predominant pain was in the knees (63% of cases). We should also note the large proportion of pains in the joints of the hands. Apparently this was associated with the need to overcome the resistance created by the pressure suit's gloves.

Series	Group	Absolute Press. in Suit, mm. Hg, atm.	Duration of Expermnt. hrs.	Cond'ns of Prelim. Desat'n	Nature of Work Performed	Energy Expenditure Avg. Kcal/hr	Energy Expenditure Peak Kcal/min	Number of Exprmnts	Number of Subjcts	Number of HDS cases	%HDS
1	2	3	4	5	6	7	8	9	10	11	12
I	1st	290-310	1-2	None	Manual stretch of shock absorber, 10-20 times/min., working 20-40% of the time.	120-150	3-4, 5	68	32	0	-
	2nd	0.38-0.41	2-4					4	4	0	-
II	3rd		1-2	20-60 min 760-550 mm Hg	Ascent of 17 cm. step, 5-20 times/minute, working 40-60% of the time.	200-400	8-12	10	25	0	-
	4th		2-4					61	17	0	-
	5th	270-290 0.36-0.38	4-6					12	12	0	-
	6th		1-2	15-30 min as press. decreased 760 to 290 mmHg	Walking or leg lifts up to 30 times/min. working 30-50% of the time,	150-200	8-10	93	30	0	-
	7th		2-4					50	30	0	
III	8th		4	60 min. 760 mmHg	Sitting and working hand or pedal controls, 5-20 times/min.	150-240	4-6	15	7	0	-
	9th	200-230 0.26-0.30	0.7	Conclud'g phase of group 7.	As in 4th and 5th groups.	100-200	8-10	60	30	0	-
	10th		0.3	Conclud'g phase of group 4.	As in 1st and 3rd groups.	200-400	8-12	42	17	4	9.5
IV	11th	175-200	1-2	60 min. 760 mmHg	As in 8th group.	120-150	3-4.5	14	9	1	7.2
	12th	0.23-0.26	2-4					64	31	4	6.3
V	13th	160-175	1-2	60 min. 760 mmHg	As in 8th group.	120-150	3-4.5	96	32	8	8.3
	14th	0.21-0.23	2-4					40	19	5	12.5
	15th		6-10					23	10	2	8.7

Table 2. Conditions and Results of Experiments using Pressure Suits.

The cited studies and observations are extremely contradictory. The basic cause of the discrepancies in the results of the studies is, evidently, the nature and intensiveness of the physical stress. No direct relationship may be found between the number of cases of HDS and the peak and average hourly energy expenditure.

We might suppose that the decisive factor is the nature of the work performed, local stress on muscles and joints, and the duration of periods of work and rest. /12

Individual peculiarities of the persons undergoing decompression and their subjective attitudes towards HDS also play a significant role.

It is nevertheless obvious that, without prior desaturization or with desaturization of limited duration (less than 1 hour), we cannot guarantee freedom from decompression sicknesses when man transitions from a normally oxygenated normobaric nitrogen-oxygen atmosphere into an environment having a 0.4 atm. or lower pressure and he is performing intensive physical work. We can speak only of a greater or lesser probability of occurrence and the reliability of this or that treatment for HDS. Laboratory research experience and actual usage of pressure suits in space flights have attested to the fact that such probabilities are extremely small. However, when it is necessary to carry out systematic and prolonged work outside a space ship, in open space, even small probabilities may become fact. So it is appropriate to review those measures materially decreasing the probability of HDS occurring. In addition to increasing the pressure within the suit, the following measures may be cited:

--special selection of cosmonauts,

--increasing desaturization time,

--replacement of the artificial atmosphere's nitrogen with a weakly soluble and poorly diffusing inert gas.