CIRCULATION AND BLOOD OXYGEN SATURATION CHANGES DURING ACCLIMATIZATION OF MAN TO MOUNTAIN CONDITIONS

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In mountain climbing to high altitudes, man experiences the effect of reduced barometric pressure of the air and the resulting lower partial pressure of oxygen, low temperature of the air and its drastic daily fluctuations, strong winds, and intense solar radiation. The considerable physical exertion which man experiences while climbing imposes excessively high demands on the organism. These can be met by a human organism thoroughly prepared by training and acclimatization.

Analysis of accidents during serious ascents indicates that they were caused to a considerable extent by inadequate training and aclimatization. Therefore, the urgent task is to develop objective criteria of the evaluation of the state of the organism and its functional capabilities under conditions of high altitudes. At the same time, there is a widespread conviction that one should not employ considerable physical exertion in functional tests at high altitudes. The majority of investigations, dealing with the reactions of the organism to physical exertion under conditions of reduced partial oxygen pressure, are carried out in a barochamber, either at moderate altitudes or on individuals inadequately trained and acclimatized.

TABLE 1. The Effect of a High-mountain Climate on the Cardiovascular System

The altitude above sea level (in meters) and location where the studies were conducted.	Number investigated	Day of investigation	Number of pulse beats per min. (mean figure and fluctuation limits)	Arterial pressure (in mm of the merc. col.)	
				Maximal	Minimal
1 800	10	1	66,6 (60—78)	120 (110—138)	81,6 (78—90)
(Shkhel'da)		15	58,8 (48—72)	119 (110—125)	78 (75—82)
4,140 (The eleven-men shelter)	10	1	78 (60—90)	122,6 (110—135)	75,2 (58—85)
		6	70,8 (48—78)	121,4 (110—135)	70,6 (60—80)
6,200 (The Eastern Victory Ridge)	30	1	93,6 (72—108)	119,6 (95—135)	75,3 (65—85)
		2	89,4 (72—102)	119 (95—135)	74,8 (65—85)
		3	85 (66—96)	118 (95—130)	71 (60—80)
7,100 (Peak Victory Summit)	10	2	114 (102—126)	114 (110—125)	58 (45—65)
		4	108 (90—126)	114,5 (110—125)	60 (50—65)

TABLE 2. Changes in Activity Indexes of the Cardiovascular System upon Three-Stage Functional Combined Test (mean data at various altitudes)

Altitude above sea level and location of conducted investigations	Day of examination	Number of observations	Type of exertion	Number of pulse beats per 10 seconds: Prior to exertion	after exertion: one min. after	two min. after	three min. after	four min. after	five min. after	Arterial pressure (in mm of mer. col.): Prior to exertion	after exertion: one minute after	two minute after	three minute after	four minute after	five minute after	Number of deviations from the normotonic type
150 (Moscow)	—	10	20 sitdown exercises	11	16	12	11	—	—	125/70	150/65	135/70	130/75	125/75	125/75	4
			15-second run	11	21	18	17	14	13	125/75	165/75	155/75	140/75	135/75	130/70	
			3-second run	13	23	18	18	16	14	130/70	170/70	160/70	145/70	135/70	135/75	
2400 (Ken-Su)	1st	10	20 sitdown exercises	13	—	—	—	—	—	140/80	—	—	—	—	140/80	
			15-second run	13	25	20	18	16	16	140/80	205/80	185/80	170/80	155/80	140/75	5
			3-minute run	16	28	24	20	18	17	140/75	210/75	190/75	185/75	150/70	140/70	
	5th	10	15-second run	11	23	17	14	12	12	120/75	200/70	180/70	160/70	140/70	125/70	3
			3-minute run	12	24	17	15	13	12	125/70	200/60	170/65	150/70	135/70	130/75	
4,400 (base camp)	1st	10	15-second run	14	23	19	17	16	16	125/75	200/70	180/75	160/75	165/75	130/75	
			3-minute run	16	25	20	19	17	16	130/75	205/70	185/70	160/75	150/75	140/75	4
	5th	10	15-second run	12	22	18	16	12	12	115/60	175/50	150/55	135/60	120/60	115/60	
			3-minute run	12	24	18	15	12	12	115/60	180/50	160/55	130/60	115/60	115/60	
5,600 (Glacier "Zvezdochka")	2nd	10	15-second run	15	26	18	17	15	15	120/75	165/65	155/65	140/70	135/70	124/70	2
			3-minute run	15	27	20	18	16	16	125/70	170/60	145/65	135/70	125/70	125/70	

The task of the present work was to study the reactions of the respiratory and cardiovascular systems of healthy and well trained individuals at high altitudes under considerable physical stress.

METHOD

We had under observations highly trained athletes: Members of the DSO group "Burevestnik (during an expedition to the Peak of Victory region in 1958) and members of the SSSR alpinist group (during the training meet in the El'brus region in the spring of 1959).

The observations were conducted at altitudes up to 7,500 m, inclusive. Of particular interest are the results obtained during the record traversing of the Pik Pobedy [Victory Peak] in August 1958, because the group spent 14 days at 7000 m altitudes (the highest point of Pik Pobedy is at a 7439 m altitude) without an oxygen apparatus — a feat hitherto considered impossible by many experts.

We examined the indexes of the state of the respiratory (vital lung capacity, respiration rate, and the magnitude of pulmonary ventilation) and cardiovascular system (the rate of cardiac contractions, arterial pressure, electrocardiogram), examined the blood for Hb content and carried out oxyhemometric determinations. To carry out the latter at high altitudes we had to construct, jointly with engineer A. K. Nelidov, a bantam semiconductor oxymeter which functioned well at various temperatures on a battery current. We always set the device at a conditional figure of 96 deg at the start of investigation, independently of the location altitude.

All these observations were dynamically conducted — starting with the departure of the alpinists for the mountains and continuing at all stages of the gradual ascents and during the descent.

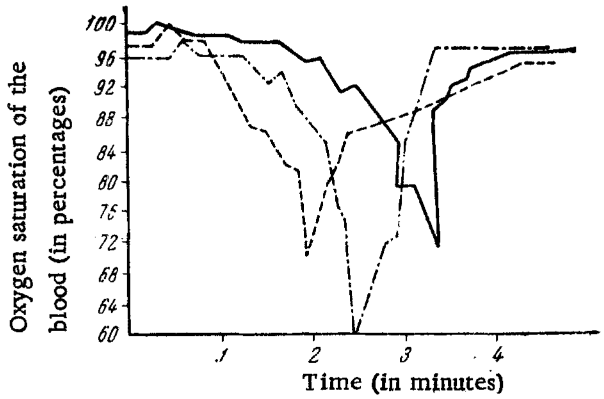

Fig. 1. Changes in the oxygen saturation of the blood upon holding the breath (according to the mean data in 10 alpinists). -·-·-Mount Frunze, 340 m. ----Glacier "Zvesdochka" 5,600 m., 1st day of stay. 1) Oxygen saturation of the blood (in percentages); 2) time (in minutes)

RESULTS

Table 1 shows the mean data of the rate of cardiac contractions in the state of rest. During the first day at an altitude of 1800 m above sea level, the pulse rate comprised on the average 66.6 beats per minute (fluctuation limits in various observed individuals were 60 to 78 per minute).

These figures do not exceed the physiological norm limits; however, they do exceed somewhat the rate characteristic of highly trained athletes in whom there is a general tendency to bradycardia. In fact, on the 15th day of stay at this altitude the average pulse rate decreased to 58.8 per minute.

At a 4,140 m altitude, during the first day the pulse rate rose on the average to 78 per minute; however, toward the 6th day it fell to 70.8 on the average and did not exceed 78 in any of the observed, in some of them constituting only 50, or even 48 beats per minute.

Of special interest are the data obtained at high altitudes. As seen in Table 1, at an altitude of 6,200 m, the pulse rate which had reached on the 1st day 89.4 beats per minute on the average, decreased on the 3rd day to 85 beats, and in some alpinists it was under 70. Finally at the altitude of 7,100 m the pulse rate, after four days, comprised 108 beats per minute on the average, and in some individuals 90°.

The arterial pressure measurements cited in Table 1 show that the maximal pressure scarcely changed at all altitudes, while the minimal pressure somewhat decreased in some instances. The arterial pressure amplitude, thus, was at times somewhat increased which could be explained by the increased systolic volume.

These results demonstrate the error of some widely held concepts that at high altitudes the pulse becomes accelerated to 108-120 beats per minute when the individual is at rest and does not decrease during the entire stay at these altitudes [1,2]. Investigations of the pulse and arterial pressure directly during considerable physical exertions (during the ascent) showed that even at high altitudes the rate of cardiac contractions most frequently varies between 130-150, the maximal arterial pressure 150-160 mm, and the minimal arterial pressure between 45-65 mm of merc. col.' Such magnitudes are often found also upon physical exertions at sea level.

Having obtained data indicating the relative moderate changes in circulation indices at various altitudes, we decided to employ as a functional test a considerable exertion (the three-stage combined functional test suggested by S. P. Letunov [3] which is generaly considered possible to use only at moderate altitudes.

The obtained data are shown in Table 2. They indicate that during the first day of stay at high altitudes the restoration period is somewhat retarded, but after a few days of acclimatization and training, the type of reaction and the rate of restoration of cardiac contractions and the level of arterial pressure indicate an entirely favorable reaction to stress. It can be assumed that, with acclimatization and training, these reactions not only do not worsen at high altitudes, but often show further improvement (Table 2).

Oxyhemometric observations were carried out prior, during, and after halting the breath.

Fig. 1 shows changes in the degree of oxygenation of the arterial blood upon holding the breath at various altitudes (according to mean data obtained on 10 alpinists).

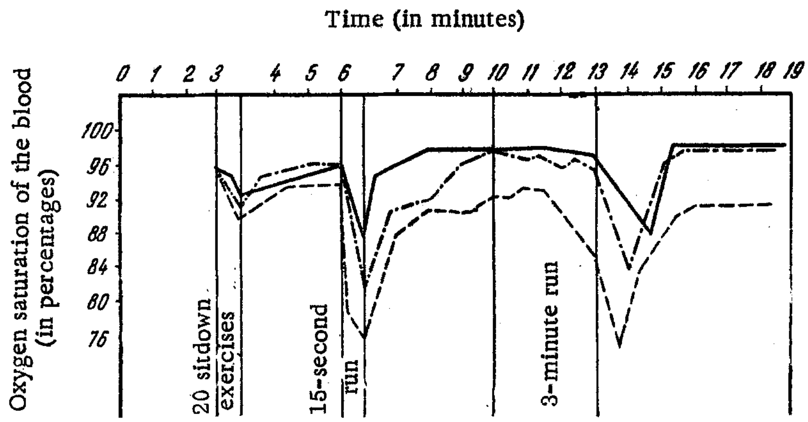

Fig. 2. Blood oxygenation during the carrying out of a three-stage, combined, functional test in an alpinist 1st class, A. K., during various acclimatization days. ----Mount Frunze, 340 m; ----Glacier "Zvezdochka," 5,600 m; 1st day of stay; -·-·- Glacier "Zvezdochka," 6th day of stay.

The length of time during which trained alpinists are able to hold their breath is very demonstrative. Four individuals were able to stop breathing for more than four minutes, the mean length of time of holding the breath being three minutes in the case of the ten observed alpinists. It shows that in trained alpinists there are higher adaptation possibilities to hypoxia than in other types of athletes.

Schematically, oxyhemometric changes upon holding the breath, can be divided into three phases: The first phase - "stable," the second phase - "hypoxemic," the third - "restorative."

The first phase lasts from the moment of holding the breath to the start of the decrease of the oxygen saturation of the blood. This phase characterizes the compensatory possibilities of the organism. The second phase (the fall of the oxygen saturation of the blood) characterizes the adaptation possibilities of the organism to hypoxemic shifts. The third phase (from the start of the increase of blood oxygenation and until its stabilization at a definite level) characterizes the rate of the restorative processes and the completeness of restoration after the acute hypoxemic shifts.

Upon an ascent to considerable altitudes during the first few days we observed a definite reduction of the breath holding time and a marked elongation of the third phase; the percentage of blood oxygenation at the end of this phase often did not reach the initial magnitudes. With the progress of acclimatization, regular changes of the oxyhemometric curve take place which are expressed as follows:

A certain reduction of the time of holding the breath, principally at the expense of contraction of the first phase, is still present. The second phase undergoes regular changes: Holding the breath lasts until the onset of a considerably greater fall of the blood oxygenation than during the initial examinations. This fact reflects a considerable increase of the adaptation possibilities of the organism as the acclimatization increases. The restoration period of blood oxygenation is considerably reduced in the process of acclimatization, and in a number of cases it becomes shorter than during the initial examinations at the sea level.

In addition, we conducted oxyhemometric tests with a measured physical exertion (at combined, three-stage, functional tests) at various altitudes and various degrees of acclimatization.

Fig. 2 shows that during the first days of acclimatization this exercise induces a marked decrease of the degree of blood oxygenation, and no complete restoration to its initial level takes place during the conduct of the test.

Subsequently, when acclimatization has been completed, the decrease of blood oxygenation during the carrying out of the combined test decreases considerably, while the rate of restoration to the initial level after the end of exercise increases and equals the restoration time at sea level; In a number of cases the restoration proceeds even faster. A parallelism is noted in the change of the extent of blood oxygenation during the combined test and the reaction of the cardiovascular system to this test, which also improves considerably at the completion of acclimatization.

The obtained data indicate that the functional possibilities of a trained and acclimatized healthy individual are quite considerable even at high attitudes. We should point out especially the need of employing tests with a considerable physical load at various altitudes, because this method permits the evaluation of the extent of preparedness of the organism to important ascents. Well trained alpinists are capable to carry them out without shifts in the state of the cardiovascular system which go beyond the limits of usual reactions.

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