DYNAMICS OF MYOCARDIAL CONTRACTIONS DURING ADAPTATION TO HIGH-ALTITUDE HYPOXIA AND AFTER ITS END

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Adaptation of rats in a pressure chamber to an "altitude" of 6000 m is accompanied by an increase in the maximum pressure developed per unit mass of the right ventricle. During adaptation to an altitude of 7300 m, the maximum pressure developed by the right ventricle increases parallel to the increase in mass of the ventricle. Stopping adaptation is followed by disappearance of hypertrophy. The function of the myocardium of the right ventricle remains unchanged during these procedures.

If animals and man remain for long periods in an atmosphere with a reduced oxygen concentration, hyperfunction of the heart takes place [2-4, 6]. Adaptive changes occur in the myocardium: an increase in ATPase activity [8], an increase in the myoglobin concentration [9], and an increase in the capacity of the coronary system [5].

In the investigation described below the functional capacity of the myocardium was studied during adaptation to high-altitude hypoxia.

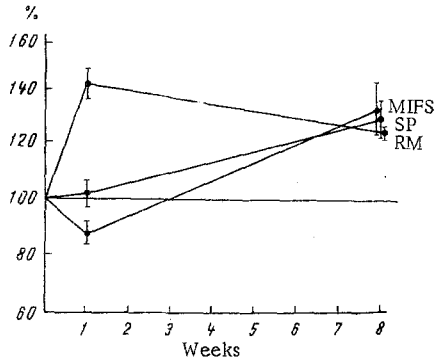

Fig. 1. Relative mass of right ventricle (RM), systolic pressure after compression of pulmonary artery (SP), and maximum strength of myocardial contraction (MIFS) of right ventricle as functions of time of adaptation. All changes during adaptation expressed as percentages of control values.

EXPERIMENTAL METHOD

Four series of experiments were carried out, series I-III on noninbred male albino rats and series IV on female Wistar rats. In series I the animals were kept in a pressure chamber under reduced atmospheric pressure corresponding to an altitude of 6000 m for 5 h daily for 1 week. In series II the animals were kept at this "altitude" for 8 weeks. In series III, for the first 4 weeks of adaptation the animals were at an altitude of 6000 m, and during the next 4 weeks at 7300 m. In series IV, during the first week the animals were gradually taken to an "altitude" of 7000 m, and they remained at that same "altitude" for the next 5 weeks. Adaptation in the pressure chamber then came to an end and the tests on these animals were carried out 6 weeks later.

Under urethane anesthesia (160 mg/100 g, intraperitoneally), after thoracotomy the pressure in both ventricles was recorded under normal conditions and during isometric contraction, produced by compression of the aorta and pulmonary artery while the heart contracted at

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TABLE 1. Indices of Contractile Function of Right Ventricle of Control Animals and Animals Adapted to "Altitude" of 7300 m

Indices studied	Control		Adaptation		Difference	
	relative physiological rest	isometric contraction	relative physiological rest	isometric contraction	relative physiological rest	isometric contraction
Relative mass of ventricle (mg/g)	0.74 ± 0.03		1.37 ± 0.04		+ 86% P < 0.001	
Heart rate (beats/min)	290 ± 15	334	350 ± 10	334	+ 21%	0
Final diastolic pressure (mm/hg)	0.7 ± 0.3	4.5 ± 0.1	3.2 ± 0.8	5.4 ± 0.3	+ 360% P < 0.01	+ 20%
Systolic pressure (mm Hg)	28 ± 2.2	90 ± 3.4	50 ± 4.3	142 ± 9	+ 79% P < 0.001	+ 58% P < 0.001
MIFS index (mm Hg/100 mg)	15.0 ± 0.75	45 ± 4.4	13.6 ± 1.3	39.5 ± 3.7	− 9%	− 12%
Contractility index (relative units)	48 ± 2.2	45 ± 1.3	51.0 ± 2.6	42.0 ± 1.2	+ 6%	− 7%

a constant and imposed frequency. The index chosen to reflect the strength of myocardial contraction was the systolic pressure within the ventricle divided by its mass [1], i.e., the "index of maximal intensity of function of the structures" (MIFS). A second index of myocardial function was the contractility index [7, 10], determined by dividing the maximum rate of development of the pressure by the pressure in the ventricle at the time when the rate of development of the pressure was maximal.

In all series the changes in both ventricles were in the same direction, but they were much more marked in degree in the right ventricle.

EXPERIMENTAL RESULTS AND DISCUSSION

The results of experiments of series I and II (isometric contraction) are given in Fig. 1. After adaptation for one week, the weight of the right ventricle was increased by 42% over its expected value for that body weight, but the maximum systolic pressure and MIFS index were not significantly changed. After adaptation for 8 weeks the body weight of the animals was reduced by 21% compared with the control, but the weight of the right ventricle in animals of both groups was the same (191 and 196 g). The relative weight of the right ventricle of the adapted animals accordingly was 25% higher than in the control. The maximum systolic pressure developed by the right ventricle of the adapted animals was 81 ± 3.6 mm Hg, which was 29% higher than in the control (63 ± 2.0). The MIFS index was correspondingly increased (Fig. 1). These results show that the maximum strength of contraction per unit mass of myocardium was much greater after prolonged adaptation than in the control.

The results given in Table 1 show that adaptation to an altitude of 7300 m led to a marked increase in the relative mass of the right ventricle, and in the final diastolic and systolic pressures in it in a state of relative physiological rest. Elevation of the systolic pressure in the adapted animals was evidently attributable to a marked increase in resistance in the pulmonary circulation, which regularly develops during high-altitude hypoxia. With the heart contracting isometrically, as the result of compression of the pulmonary artery, the systolic pressure in the right ventricle was increased by 58% over the control, whereas the MIFS index was the same as in the control. In other words, the marked increase in strength of contraction of the whole ventricle was due entirely to the increase in its mass, in the absence of any significant changes in the strength of contraction generated per unit mass of muscle tissue.

In the experiments of series IV, the dynamics of mass of the heart and its contractile function was studied after the end of prolonged adaptation to high-altitude hypoxia. In this series, by contrast with the previous series of experiments, female Wistar rats were used. In these animals the degree of hypertrophy was lower than in noninbred animals, namely 30%. The indices of contractile function were not significantly different from the control by the end of adaptation. Six weeks after the end of adaptation the relative mass of the ventricle was reduced to the control level, and the indices of myocardial contraction also were indistinguishable from the control.

Hence, during disappearance of the moderate hypertrophy observed in these experiments, the contractile function of the myocardium remained substantially unchanged. The fact that even a much greater degree of hypertrophy of the heart disappears after the end of adaptation was already known [3,4].

It can be concluded from these results that hypertrophy of the heart developing in animals during the adaptation to high-altitude hypoxia of moderate severity is accompanied by an increase in cardiac function on account both of an increase in function of the muscle tissue and an increase in the mass of the tissue. Hypertrophy of the heart produced by adaptation to a more marked degree of high-altitude hypoxia leads to an increase in cardiac function entirely on account of an increase in the mass of heart muscle tissue.

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