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RELATIVE HYPERTROPHY OF THE RIGHT VENTRICLE IN SILVER FOXES SELECTED FOR DOMESTICATION

N. K. Eriskovskaya, T. A. Leont'eva,
Yu. G. Tsellarius, L. N. Trut,
and D. K. Belyaev

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To analyze the genetic mechanisms of domestication of animals, for the last 25 years silver foxes have been bred in the Institute of Cytology and Genetics, Siberian Branch, Academy of Sciences of the USSR, for domestication. Previous investigations have shown that domestication of animals is accompanied by the appearance of some special physiological and morphological features [4, 5]. In particular, the study of the internal organs showed that the weight of the right ventricle is increased to some degree in animals capable of domestication compared with those which are incapable. The investigation described below was devoted to a study of this problem.

EXPERIMENTAL METHOD

Experiments were carried out on 88 silver-black foxes aged 2-4 years, obtained at the Experimental Game Farm of the Institute. The animals investigated included 23 male and 20 female foxes bred for domesticated behavior (capable of domestication) and 23 male and 22 female foxes obtained from a State Farm Population, not subjected to corresponding selection (incapable of domestication). The groups were selected in accordance with the analog principle of age composition.

After electrocution the animals were weighed and the heart was removed and fixed with 4% depolymerized paraform in 0.1 M phosphate buffer, pH 8.0 [10]. This fixation did not appreciably change the weight of the tissues. The walls of the right ventricle (RV) and the wall of the left ventricle with ventricular septum (LV) were isolated from the fixed hearts and weighed separately.

For stereologic study at light and electron-microscopic levels of the relative and absolute total volumes and surface areas of the myocardial structural components [1, 11, 12, 14] groups of six male foxes capable of domestication and six incapable, of identical age composition and all killed on the same day, were chosen. The technique of alkaline dissociation of the myocardium [3, 7] was used on these same animals to determine the total number and concentration of the muscle cells and of their nuclei in RV.

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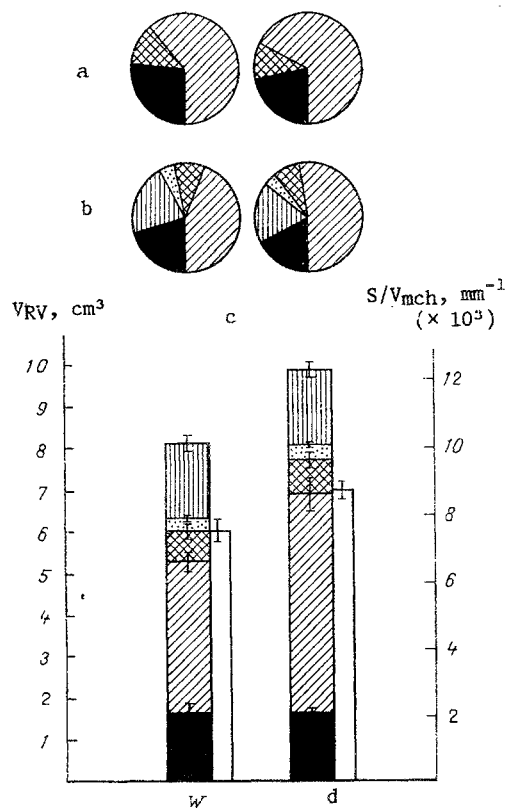


Fig. 1. Relative and absolute relationships between structural components of the myocardium of RV in foxes incapable (w) and capable (d) of domestication. Black regions denote total volume of mitochondria (V_{mch}); obliquely shaded, total volume of myofibrils (V_{mf}); cross-hatching, total volume of other components of cardiomyocytes (V_{oth}); dotted region, total volume of capillary bed (V_c); vertical shading, total volume of stroma of myocardium (V_{st}); unshaded columns, ratio of surface area of mitochondria to their volume (S/V_{mch}). a) Relative volumes within muscle fibers, b) relative volumes in whole myocardial tissues, c) absolute total volumes of structural components of myocardium of RV (ordinate, left) and ratio of surface area of mitochondria to their volume (ordinate, right) in male foxes.

EXPERIMENTAL RESULTS

A statistically significant ($P < 0.001$) increase in both the absolute and the relative weight of RV was observed (Table 1) in the animals capable of domestication compared with those incapable. In the male foxes capable of domestication the weight of RV was on average 21% greater, and in female foxes 18% greater, than in those incapable of domestication. A tendency was observed (not statistically significant) for the weight of LV to increase, but it must be recalled that LV was weighed together with the ventricular septum, and the tendency for its weight to increase could have taken place on account of the part of the ventricular septum which belonged to RV. The total weight of the ventricles was increased by 10% in males and by 8% in females. The body weight of females is less than that of males, and the weight of their heart is correspondingly smaller, and for that reason the indices (ratio to body weight) of the ventricles of the heart in males and females were similar in value. In both the indices of RV were higher in the groups of animals capable of domestication. The ratio of the weight of RV to the weight of LV also was increased.

Counting the number of muscle nuclei per milligram of myocardial tissue showed that in animals capable of domestication the concentration of nuclei in RV was 21% lower than in the animals incapable of domestication. The weight of RV in the animals capable of domestication was greater by about the same degree. When the total number of muscle nuclei was calculated, similar values were accordingly obtained (Table 2).

TABLE 1. Weight and Index (ratio to body weight) of Ventricles of Foxes Incapable (w) and Capable (d) of Domestication ($\bar{X} \pm m$)

Parameter	Males		Females	
	w	d	w	d
Number of animals	23	23	22	20
Body weight, g	6346 \pm 187	6253 \pm 140	5156 \pm 156	5131 \pm 112
Weight of ventricles, g	36,67 \pm 0,78	40,20 \pm 0,39**	30,70 \pm 0,52	33,28 \pm 0,83 ‡
Weight of RV, g	8,58 \pm 0,22	10,40 \pm 0,27**	7,51 \pm 0,18	8,83 \pm 0,20 **
Weight of LV, g	28,09 \pm 0,66	30,10 \pm 0,85	23,16 \pm 0,49	24,68 \pm 0,64 †
Index of ventricles ($\times 10^5$)	588 \pm 20,4	648 \pm 18,5*	599 \pm 12,5	652 \pm 18,4 †
Index of RV ($\times 10^5$)	137 \pm 4,17	168 \pm 4,80**	146 \pm 3,30	169 \pm 5,00 **
Index of LV ($\times 10^5$)	452 \pm 17,4	480 \pm 14,1	452 \pm 11,0	483 \pm 13,8
Ratio of weight of RV to wt.of LV ($\times 10^3$)	311 \pm 7,88	349 \pm 4,79**	327 \pm 9,0	351 \pm 4,64 †

Legend. *P < 0.05, †P < 0.02, ‡P < 0.01, ***P < 0.001.

In foxes, as in many mammals [6, 9, 13], most cardiomyocytes are binuclear. Mononuclear cells accounted for fewer than 20%, and tri- and quadrinuclear cells were rare. There was no difference in the relative percentages of the various muscle cells in foxes capable and incapable of domestication. There was likewise no difference in the total number of cardiomyocytes in RV. The increase in weight of RV of the heart in foxes capable of domestication thus took place without any change in the total number of muscle cells and of their nuclei. This phenomenon can be explained in two ways: either the muscle cells are hypertrophied or the weight of the interstitial tissue is increased.

To study these alternatives, a stereologic investigation of myocardial sections at light and electron-microscopic levels was undertaken (Fig. 1).

Measurement of the bulk density of the components of the muscle cells in foxes capable of domestication revealed a decrease in the relative total volume of the mitochondria (21% compared with 27% in animals incapable of domestication). The relative volume of the myofibrils was increased a little (68% compared with 62%). The relative volume of the myocardial stroma, determined in semithin sections, was a little lower in animals capable of domestication (18% compared with 23%), but the relative volume of the muscle fibers was correspondingly increased. When relative volumes were converted to absolute it was found that the total volume of the mitochondria was the same in animals capable and incapable of domestication, whereas the volume of the myofibrils was significantly (P < 0.01) increased. The total volume of the myocardial stroma was the same in animals of both groups.

An increase in the ratio of the surface area of the mitochondria to their volume also was found in animals capable of domestication. This may be due both to a change in shape of the mitochondria and to an increase in the number of smaller mitochondria, while their total volume remained the same. It is evident that both these explanations are valid (Fig. 2).

The stereologic data are very similar to results obtained by the writers previously when studying the myocardium of rats, in which hypertrophy of the heart was induced by adaptation to high altitude hypoxia [12]. In both cases the weight of the myocardium increased mainly on account of an increase in weight of the myofibrils, whereas the total volume of the mitochondria remained unchanged, and their surface area was increased. The only significant difference is that in hypoxia an increase was observed in the volume of myocardial stroma and, in particular, there was an increase in the volume of the capillary bed, whereas during domestication this increase was not marked. As regards the muscle cells themselves, changes here were identical, and they evidently reflected relationships arising in the cardiomyocytes during hypertrophy from different causes.

The investigations showed an absolute and relative increase in the weight of RV in foxes selected for domestication compared with ordinary foxes of the wild population, and associated with hypertrophy of the cardiomyocytes while the total number of muscle cells and of their nuclei remains the same. The number of cells and, possibly, the total volume of the genome of this particular organ are evidently species-specific features that were not changed during selection. Meanwhile a certain factor appeared which threw a greater functional load on RV of the foxes capable of domestication. This factor could be a change in the balance between sympathetic and parasympathetic effects.

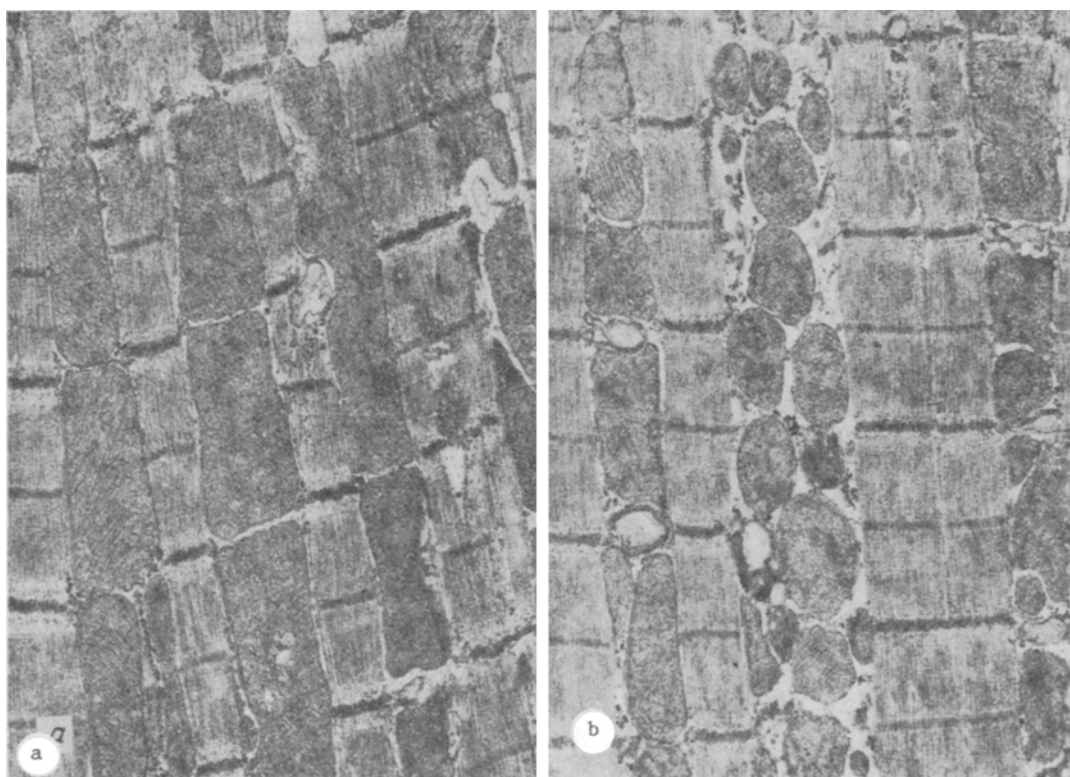


Fig. 2. Typical areas of myocardium of RV of foxes incapable (a) and capable (b) of domestication. In the animal capable of domestication the myofibrils are thicker and the mitochondria smaller. 20,000 \times .

TABLE 2. Number of Cardiomyocytes and of their Nuclei in Right Ventricle of Male Foxes Incapable and Capable of Domestication ($\bar{x} \pm m$)

Parameter	Animals incapable of domestication	Animals capable of domestication
Number of animals	6	6
Weight of RV, g	$8,62 \pm 0,36$	$10,45 \pm 0,64$
No. of myocyte nuclei in 1 mg ($\cdot 10^3$)	$27,6 \pm 1,84$	$21,8 \pm 0,63$
Myocytes, %:		
mononuclear	$16,0 \pm 1,36$	$19,1 \pm 1,59$
binuclear	$80,2 \pm 1,29$	$77,1 \pm 1,70$
trinuclear	$0,62 \pm 0,10$	$0,48 \pm 0,14$
quadrinuclear	$3,20 \pm 0,60$	$3,07 \pm 0,50$
Total number of myocyte nuclei ($\cdot 10^6$)	$237 \pm 18,0$	$226 \pm 8,9$
Total No. of muscle cells ($\cdot 10^6$)	$124 \pm 9,3$	$120 \pm 5,1$

It has been shown [8] that the domestication process in foxes is accompanied by changes in activity of their monoaminergic systems. There is also evidence that the arterial pressure in the pulmonary circulation is higher in domesticated species of animals than in closely similar species of wild animals [2]. Marked hypertrophy of RV discovered in silver-black foxes bred for domestication is evidently a secondary effect of the genetically determined changes in neurohumoral regulation which lie at the basis of the domestication process.

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