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GENERAL BIOLOGY

The Reproductive Strategy and Immune Status of Rodents in an Environment Altered by Industrial Activity

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The nature and mechanisms of animal population adaptation to chronic irradiation is one of the most important problems of modern radioecology. The results of long-term monitoring of mouselike rodent populations in the head portion of the Eastern Ural radioactive trail (EURT) show numerous quantitative and qualitative disturbances in the hemopoietic and immune systems of the animals [1, 2], as well as substantial cytogenetic [3] and morphogenetic [4] alterations. At the same time, the numbers of dominant rodent species in the EURT zone have remained the same as in the background areas for many years, and their fertility is sometimes even higher than the control values [1, 5]. Functions of the immune system are diverse, it is involved in maintenance of the cytogenetic homeostasis, control of offspring quality [6], adaptation [7], and control of ontogeny [8]; immune reactivity is also related to demographic processes. Therefore, it may be presumed that disturbances caused in animals by radioactive contamination of the environment are also related to alteration in the immune system.

The results presented below demonstrate that disturbances in the controlling (eliminating) and regulatory functions of the immune system are leading factors of the increase in the reproduction rate of mouselike rodent populations of areas altered by industrial activities and may be regarded as mechanisms of adaptation to radioactive contamination.

Experiments were performed to analyze the reproductive characteristics of laboratory mice under the conditions of immunosuppression, and the results of the model experiment were compared with the reproductive parameters of rodents from the EURT and neighboring areas. The immunosuppressant Cyclophosphanum was intraperitoneally injected to females from the experimental group (strain CBA) during seven days before mating; control animals were injected with physiological saline (a total of 84 mice were used). The immunomodulator effect was verified by morphological, physiological, and immunohematological parameters. The fertility parameters and embryo loss were calculated, the total number of the offspring was recorded, and the changes in body weight during early ontogeny were monitored. The Excel software package was used for treatment of the data.

The morphological and physiological verification of the immunosuppressant effect showed that the groups significantly differed in almost all indices of internal organs (Table 1). Regarding the hemopoietic system, the experimental group was characterized by a considerable decreased in the cellular density of the bone marrow and spleen, a considerable leukopenia accounted for by a decrease in the main populations of leukocytes

Table 1. Morphophysiological characteristics of female CBA mice treated with an immunosuppressant (organ indices)

Group	Index, ‰					
	thymus	heart	liver	spleen	kidney	adrenal gland
Experiment	1.0 ± 0.1**	5.8 ± 0.3**	38.5 ± 1.7*	2.6 ± 0.2**	6.7 ± 0.4	0.6 ± 0.03**
Control	2.7 ± 0.1	6.9 ± 0.1	45.2 ± 1.4	5.0 ± 0.2	5.6 ± 0.4	1.0 ± 0.03

Note: The organ index is the ratio of its weight (mg) to the body weight (g). Significance of differences: * $p < 0.05$; ** $p < 0.001$.

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Table 2. The total number of offspring, litter size, and sex ratio in the offspring of CBA mice

Group	Total number of offspring	Mean number of offspring per litter	Sex ratio	
			number of females	number of males
Experiment	217	6.2 ± 0.2*	141	76
Control	161	5.2 ± 0.2	79	83

* Significant difference ($p < 0.001$).

(neutrophils and lymphocytes), and structural alterations (the nuclei had festooned margins, and their structure was finer than that of the nuclei of mature lymphocytes). These changes in leukocyte populations are known to lead to substantial immune disorders [1, 2].

In the experimental group, a suppressed immunity of the female mice was accompanied by an increase in the proportion of reproductively active animals (by 10%) and their fertility (Table 2) and a decrease in embryo loss (Fig. 1) and the proportion of females with embryo loss (Fig. 2). The total number of newborns was increased; they exhibited a marked hypotrophy during early ontogeny. Females were noticeably prevailing in the offspring (Table 2). Shifts in sex ratio were earlier [9] observed in rodents from regions contaminated with radioactive wastes. On the other hand, it is well known that the chromosomal mechanism of sex determination in mammals ensure equal proportions of males and females at birth, and the changes in the sex structure of a population with time, as a factor of reproduction and changes in population size, have a certain effect on microevolution [10].

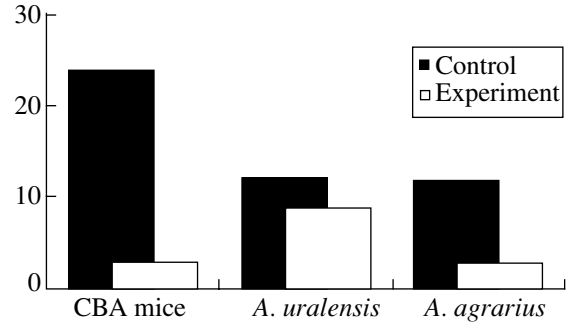

Fig. 1. Embryonic loss in CBA mice in a model experiment and in rodents from the EURT zone and neighboring areas.

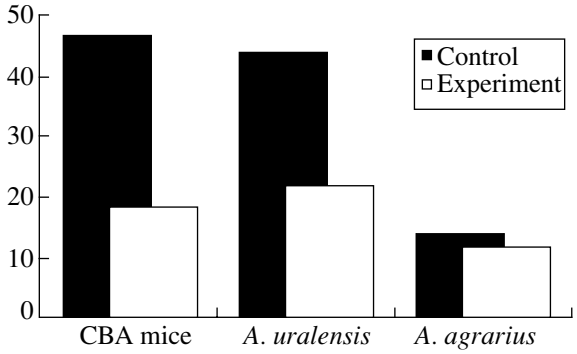

Fig. 2. The proportion of females that had embryonic loss among CBA mice in a model experiment and in rodents from the EURT zone and neighboring areas.

The observed changes in the reproductive characteristics of inbred mice and some parameters of their offspring were assumed to result from disturbances of the functional activity of the immune system, which leads to a decrease in the immune control of cytogenetic homeostasis and reproductive function. The relationship between chromosome aberration rate and immunohematological characteristics under the conditions of anthropogenic stress has been demonstrated in a study on the common vole twin species (the *Microtus arvalis* group) [11].

Our analysis of the reproductive parameters of *Apodemus uralensis* Pall. and *A. agrarius* Pall. from the EURT zone and neighboring areas showed a lower proportion of females with embryo loss (Fig. 2) and the embryo loss rate in rodents from a radiation biogeocenosis (Fig. 1). There are published data on an increase in fertility and decrease in embryonic death in *Clethrionomys glareolus* Schreb. trapped near copper smelteries in the Middle Urals [12] and in *Microtus oeconomus* Pall. inhabiting a uranium–radium area for 70 years [13]. An increase in litter size accompanied by decrease in lifespan and increase in mortality has been observed in rodents from family Heteromyidae irradiated under laboratory conditions (with the use ^{137}Cs as a source of radiation) [14].

Summarizing the results of our experiments, literature data, and materials of field observations, we may assume that an increase in reproduction rate is one of the adaptation mechanisms maintaining rodent numbers in the environment deteriorated by industrial activities, the immune system playing an important role in this process. Impairment of the controlling and regulatory functions of the immune system of rodents inhabiting the head portion of the EURT leads to an increase in the proportion of animals with a considerable genetic load (because of inadequate elimination of defective genetic material at various stages of its development) and retention of the load in the population gene pool if adapted individuals have reproductive value.

Numerous data on genomic instability and the transmission of radiation-induced genetic instability between generations [15] indicate that the changes in the functional characteristics of the animal immune system possess adaptive value and serve as a material for natural selection.

Thus, the impairment of the controlling (eliminating) and regulatory functions of the immune system is the leading factor of the increase in the reproduction

rate of mouselike rodents living in the environment altered by industrial activities (despite morphological, physiological, and other defect and pathologies as long as they are compatible with life) and is one of the mechanisms of radioadaptation.

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