

The Influence of Chronic Radiation Exposure in Chernobyl Exclusion Zone on Mammals

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Abstract:

Given the emission of large amounts of radionuclides during Chernobyl nuclear accidents, the physical condition of mammals in Chernobyl Exclusion Zone (CEZ) is worth conducting research to provide humans with new insights into ecology, evolutionary biology and other fields. Recent studies have proved the coexistence of vulnerability and resilience in mammals, under chronic radiation. On the one hand, mammals in CEZ do suffer from multiple types of damage on the aspect of cells, genes and population size. On the other hand, by developing adaptive traits, they demonstrate incredible vitality. However, detection of critical attitudes in mammals is insufficient in details, including genes with specific functions and confirmation of mechanism and pathways. In the future, it is important to investigate the whole genome and compare with the mammals in natural living status for several generations. Additionally, mammals living in CEZ are correlated with survival in tumor, which can provide a perfect model for research in human cancer.

Keywords:

Chernobyl Exclusion Zone, Chronic Radiation, Mammals, Mutagenic Stress

1. Introduction

Chernobyl Nuclear Disaster (CED), which happened in 1986, was a catastrophe for all humans. Virtually immeasurable radionuclides were emitted into the soil and atmosphere, including iodine-131, cesium-137, strontium-90, and various plutonium isotopes [1]. This catastrophe directly resulted in large scale of evacuation, a sharp reduction in the number and diversity of flora and fauna and severe harm to the environment. As for the long-term impacts, damage caused by ionizing radiation (IR) to the genetic level will be passed down to several generations [2]. With all impacts of CED, numbers of researchers have been devoting to measure radiation intensity and explore the survival status of wild fauna and flora in CEZ.

Collectively, animals in the exclusion zone exhibit the concomitant occurrence of the vulnerability to mutagenic stress and resilience [1]. A wide range of research has demonstrated that mutation rates, chromosomal aberration and transmissible genetic instability in the species in the exclusion zone are supposed to increase after chronic exposure to IR [1]. For example, a research focused on bank voles (*Clethrionomys glareolus*) within a 400-km radius of the Chernobyl Nuclear Power Plant (CNPP)

revealed that cytogenetic aberration and embryo mortality rates in every generation significantly increased when historic doses were on a scale of 20-51 mGy[3]. However, evidence also shows that some species have evolved adaptive response, such as tree frogs in Chernobyl, which exhibited darker dorsal skin[4]. It is assumed that dark skin, which contains melanin, can cope with radiation energy and offer cellular protection [4]. Based on existing studies, researchers have found that the exclusion zone supports the abundance of mammalian populations [5]. Relative abundances of elk, roe deer, red deer and wild bear in CEZ are basically comparable to that in unpolluted areas and wolf abundance is even 7 times higher than uncontaminated areas [5]. Nonetheless, some studies have reported a decline in abundance of animals [6]. These two entirely contradictory results is a reflection of the combined effect of multiple factors, radiation dose, human influences, individual variability, experimental methods, to name but a few.

What is more noteworthy is that a paper published in 2020 pointed out that the real and complex circumstance the wildlife encounters cannot be simply measured by ambient dose rates or soil concentration activities [7]. Instead, it is essential to take both internal and external contributions into account [7]. Specifically, this relationship involves in radionuclides attributes (species of radioactive elements and emission energy) and traits of different animal species (age, diet, habitat and environmental usage patterns) [7]. Consequently, as far as the chronic influence of radiation exposure in CEZ on mammals is concerned, the complex interaction mechanism of multiple factors is a main problem. The restriction comes from cross-sectional research framework, which means research usually focuses on one generation, so it is limited to sample magnitude and temporal solution [1]. That is why existing research leads to varying outcomes. It is urgent to adopt a vertical and cross-generational approach, in order to detect critical attitudes more precisely, including the persistence of mutations, heritable genetic instability and adaptive responses [1].

This review aims to systematically analyze available literature on mammals in CEZ. Focusing on dual responses to chronic radiation exposure, this review intends to investigate the vulnerability to mutagenic stress, including the decline in the abundance of populations and inheritable damage at the molecular biology level. Simultaneously, remarkable resilience exhibited in mammals, adaptive traits and diverse strategies for survival, is also examined in this review. At last, this article will present future perspectives according to published papers and leading international conferences.

2. Vulnerability to Mutagenic Stress

2.1. Reduction in the abundance of populations

As discussed above, there are two completely different results of the change in the abundance of populations. In early studies, researchers have found an increase in the abundance of mammals [5]. To some extent, studies like this guided the academic community and the public to believe the viewpoint that even if the severe radiation exists, mammals in CEZ are able to have a better living circumstance. However, it is worth noting that this study is based on a macroscopic perspective. It did not consider the difference of radiation effects in CEZ. In terms of the radiation in CEZ, its distribution is too uneven to form a stable and sustained selection pressure [8]. Therefore, abundance differentiation due to radiation dose absolutely exists, which means it is not objective to draw a unified conclusion.

A paper published in 2023 has provided a deeper insight into this topic. The researchers selected three groups of dogs, 132 from CNPP, 154 from Chernobyl City and 16 from the city of Slavutych [9]. The radiation effects on these three groups of samples gradually decreased. Using 129,497 genome-wide single-nucleotide polymorphisms (SNPs), they found that dogs in CNPP exhibited characteristics of high inbreeding, low genetic heterozygosity, strong reproductive isolation and low biodiversity, which means gene flow is mostly between the individuals in the scale of CNPP[9]. While the other two groups did not show obvious influence [9]. Overall, confronted with high radiation doses and intense radiation impacts, the abundance of mammals definitely declined, while those in areas with lower radiation effects showed similarity with a pattern of natural growth.

2.2. Cellular and genetic damage

Chernobyl nuclear accident has released multiple kinds of radionuclides, which bring high levels of IR and can cause lethal damage to mammals in CEZ [10]. At the level of cells and genes, IR can cause multiple damage to DNA, such as double-strand breaks, which are more lethal [2]. Clustered de novo mutations(cDNMs), including de novo copy number variants(CNVs) and insertion/deletion events(indel), are clusters of 1–4 single-nucleotide variants(SNVs) or clusters of 1–2 SNVs and indels within a few base-pairs of each other [11]. It is found that compared to control groups, the frequency of cDNMs in the progeny of irradiated fathers obviously increased [11]. This result can be explained by the induction of clustered damaged sites in irradiated males germline and cluster DNA-damaged sites are characterized by two or more lesions within one or two helical turns, which are considered as a signal radiation exposure [11]. In addition, cDNMs share the core repair pathways with double-strand breaks [11]. In a human-targeted study, researchers found that in the offspring of irradiated parents, the cDNM count exhibited a markedly increase and there is a potential association between doses of radiation and the cDNM count in the offspring [12]. Collectively, cDNM can be regarded as the indicator of the degree of radiation damage and has close relationship with lesions caused by IR.

By comparison, de novo mutations (DNMs), which are defined as random, dispersed and independent substitutions of one base in the genome, did not show obvious increase in the offspring of irradiated males [11]. There is evidence shows that DNMs and IR have little association with each other. Instead, the time of the replication of DNMs has a strong correlation with paternal age, whereas the opposite is true for chromatin accessibility, chromatin modifications and recombination rate [13]. Additionally, a study found that the children of the parents who had been exposed to IR did not seem to experience an increase in the number of DNMs [14].

To conclude, DNMs represent the overall genetic risk in the offspring, with characteristics of dispersity and universality, while cDNMs exhibit high radiation specificity and are better at reflecting molecular damage [12].

Furthermore, in terms of the oxidative stress, the main direct impact of IR on cells is producing reactive oxygen species(ROS) from water, which is also the primary reason of physiological and pathological responses in radiation exposure [8]. In chronic exposure to IR, with the hypothetical pathway of producing excessive ROS, mitochondrial function is anticipated to be impaired [8]. These results are applicable to the IR in CEZ and IR in CEZ is more penetrating, which can cause more serious

damage [8]. Simultaneously, IR can trigger senescence in normal cells, resulting in cell cycle arrest, mutations, cancer or cell death [2].

What is noteworthy is that oxidative stress will cause multiple types of converging and cross-cellular responses, thus, it is too hard to confirm the causality of different endpoint results [8]. Usually, these stress responses can stimulate cells under radiation stress to survive, however, as a trade-off, metabolism will be remodeled, which can probably cause detrimental physiological effects on individual level [8].

3. Resilience

3.1. Adaptive responses

In some early studies focusing on mammals in CEZ, it is found that after the accident outbreaking for 30 years, the population size in CEZ has not been influenced and even increases [5]. Therefore, it is sensible to infer that mammals in CEZ have made adaptive responses.

Back to the research of bank voles (*Clethrionomys glareolus*), compared to doses between 20-51 mGy, cytogenetic aberration and embryo mortality rates will not increase continuously and tend to stabilize, on a scale of 51-356 mGy. This result suggests that this dose range activates their adaptive protection mechanism to resist the damage of radiation [3]. To be specific, on average, Chernobyl fibroblasts of bank voles are more resistant to oxidative and chronic DNA stress [15]. According to experimental results, different from the control group, after the DNA damage, Chernobyl fibroblasts can arrest stably at G2 phase, while homologous recombination, the most mechanism of repairing dsDNA breaks, is the most active [15]. Therefore, a conclusion can be drawn that the radiation in Chernobyl select adaptive traits of bank voles' cells in order to resist oxidants and help cells recover from DNA damage [15].

3.2. Survival strategies

Previously, several studies have shown that dogs can be regarded as a sentinel species for the health influence of a wide range of exposures to the environment [16]. Researchers found 391 significant abnormal loci in dogs' genome [16]. 52 of these genes, approximately 67 outlier SNPs, probably have association with terms in gene ontology(GO) which are related to the contamination in the environment of nuclear power plants, including DNA repair, cell cycle signaling, responses to radiation, calcium binding and immune function [16].

Furthermore, a study, based on gray wolves (*Canis lupus*) in the CEZ, had confirmed the activation of neutrophil and macrophage signatures and inhibition of multiple adaptive immune traits via gene set variation analysis(GSVA), including immune checkpoint targets also exhibiting significant difference [17]. Meanwhile, 23 genes overexpressed in CEZ wolves have significant positive prognostic impact on more than 2 types of human tumor [17]. In this case, researchers drew a conclusion that changes in CEZ wolves' genome are likely shaped by chronic radiation and the wolves have adapted to multigenerational exposure to radiation [17].

4. Future Perspectives

4.1. Potential research directions

Firstly, after nearly 40 years, humans have not got a comprehensive insight into broader ecological consequences in CEZ, including impacts on biodiversity, community structure and ecosystem, which is a direction worth pursuing [1]. Furthermore, research comparing CED with Fukushima Daiichi nuclear accidents is of profound significance. This research approach enhances the understanding of the universal and site-specific patterns of adaptation and vulnerability [1]. Additionally, as for humans, the enrichment of positive prognostic genes in CEZ wolves provides a treasured model for exploring genetic basis of cancer immunity and promotes the understanding of the resilience of human cancer [17].

4.2. The enlightenment for humanity

After the nuclear accidents, many researchers have been conducting experiments in CEZ, thus, data from these experiments provide an improved understanding of chronic ecological consequences of nuclear accidents [18]. Also, policy makers can make use of these data to develop effective management and safety protocols for wild animals in other highly contaminated landscape [18]. In addition, as a natural laboratory, Chernobyl contributes to humans' understanding of the influence of multiple factors on physiology, evolution and adaptation of wild fauna and flora.

5. Conclusions

Collectively, for the influences of chronic radiation in CEZ on mammals, it is well established that vulnerability to mutagenic stress and resilience occur simultaneously. It has been proved that IR in CEZ can harm mammals, but some of them have also developed adaptive traits. However, research targeted animals in CEZ is restricted to certain regions, conventional methods and specific species. Therefore, it is necessary to develop new methods and framework to get a comprehensive understanding of impacts of Chernobyl nuclear accidents in wider fields, including medicine, ecology and cell biology.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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