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Effects of Environmental Radioactive Pollution on the Cardiovascular Systems of Ural Region Residents: A Comparative Study

Ekaterina Konstantinova[1]*, Yuliya Shalaumova[1], Tatiana Maslakova[1], Anatoly Varaksin[1] and Andrei Zhivoderov[2]

[1] *Institute of Industrial Ecology, Ural Branch of Russian Academy of Sciences, 20 S. Kovalevskaya St., Ekaterinburg, Russia*

[2] *Ural Federal University named after the first President of Russia B. N. Yeltsin, 19 Mira St., Ekaterinburg, Russia*

**Corresponding e-mail: k_konst@ecko.uran.ru; kontantinovaekateri@gmail.com*

ABSTRACT

Objective: *The aim of this comparative study was to evaluate the effects of radioactive pollution in river water and confounding risk factors on the prevalence of cardiovascular symptoms in people living in the Ural region.* ***Methods:*** *We selected this region as a case territory for study because it is exposed to chronic ionizing radiation. The area is composed of coastal localities situated along the Techa River, into which liquid radioactive waste materials have been released. As a control, we selected settlements that were not subjected to ionizing radiation.* ***Results:*** *We found a statistically significant relationship between radioactive contamination of a territory and the prevalence of pathologies of the cardiovascular systems of people living in the Techa riverside villages (OR=2.31, p<0.001). The influence of covariates (gender, age, overweight status, and others) on the development of cardiovascular pathologies was analyzed. Some of these factors have been recognized as confounding factors. After accounting for confounding factors, the odds ratio for the impact of radiation on the prevalence of pathologies of the cardiovascular system decreased to (OR=1.58, p=0.02).* ***Conclusions:*** *Statistically significant gender and age differences were observed in the prevalence of pathologies of the cardiovascular system in residents of radioactively contaminated areas compared to residents of control areas. These differences show a more pronounced reaction to contamination in older residents, residents with an overweight status and residents with meteotropic reactions.*

Keywords: Radioactive contamination, Techa river territory, Confounders

Abbreviations: CCS: Condition of the Cardiovascular System; BMI: Body Mass Index; RR: Relative Risk; CI: Confidence Interval; OR: Odds Ratio.

INTRODUCTION

The study of health effects of radioactive contamination of the Techa River is of great interest due to the necessity of estimating the effects of long-term low-dose radiation exposure to the body [1,2]. Individuals exposed to ionizing radiation suffer from different types of diseases and multiple diseases more frequently than unexposed individuals [3]. This observation can be explained by the increased stress of the body's compensatory mechanisms. In recent years, cardiovascular diseases have ranked first among non-communicable diseases, in the structure of general morbidity in the Russian Federation [4]. Previous studies of residents in the radioactively contaminated Techa riverside villages, which have been exposed to low doses of ionizing radiation, have shown similar results [5]. The excess risk of cardiovascular disease was detected only 10-20 years after exposure to low doses of radiation [2]. Ionizing radiation exposure can either increase the effects of generally recognized risk factors for cardiovascular diseases [5] or be an independent cause of pathology [2]. The precise role of chronic ionizing radiation in the development of cardiovascular system pathologies remains ambiguous, given the confounding factors of cardiovascular risk [1].

Traditionally, great attention is paid to confounding factors when assessing the risk of cardiovascular diseases, as such factors can distort the effect of the main investigated risk factor (in this case, the effect of radiation).

This study analyzes the impact of radioactive contamination of river water on the prevalence of cardiovascular pathologies among the population, taking into account confounding factors (gender, age, overweight, sleep disturbance, and meteosensitivity). This approach allows us to identify the most vulnerable groups of the population, enabling targeted prevention and treatment strategies for cardiovascular disease.

MATERIALS AND METHODS

We have distinguished two territories in the Ural region to perform a comparative study on the role of low-dose exposure to ionizing radiation in the development of cardiovascular pathologies (Figure 1). The case territory has been exposed to chronic ionizing radiation. It includes coastal localities situated along the Techa river, into which liquid radioactive waste materials were released due to several radioactive incidents during the initial activities of the Mayak Production Association. Because of a series of radioactive accidents from 1949 to 1956, approximately 76 million cubic meters (m^3) of effluent water with a total beta activity of 2.75 MCi was released into the Techa River [6].

The main dose-forming radionuclides are the isotopes 90Sr and 137Cs, which have a half-life of 28.8 years and 30.2 years, respectively.

Long-term combined external and internal exposure of the Techa River residents was caused by the use of river water and contaminated locally manufactured food products. To the present day, the Techa river contamination remains a significant source of exposure for some inhabitants [7]. The average annual volumetric activity of the 90Sr isotope in the water of the Techa river in the areas of coastal settlements in 2015 amounted to 6.07-6.46 Bq/l [8]. These values are 1.2-1.3 times higher than the population intervention level according to Radiation Safety Standards (4.9 Bq/l) [9], and they are three orders of magnitude higher than the background levels of rivers in Russia (5.02 MBq/l) [8]. As a control territory, we selected settlements located near the Techa river that have not been exposed to ionizing radiation.

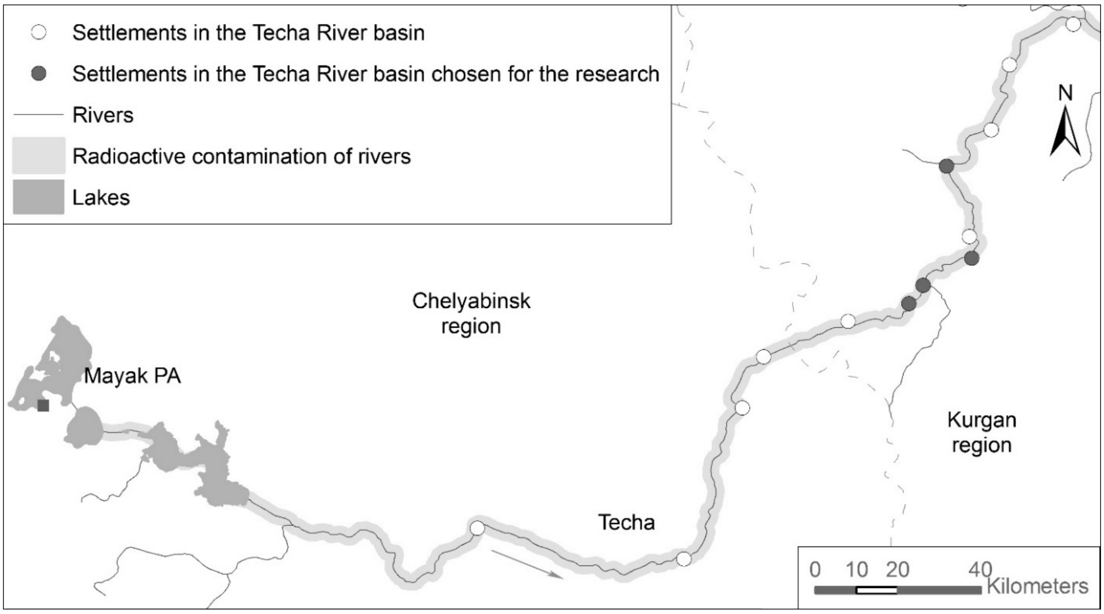

Figure 1 Map of the study area showing settlements in the Techa river basin

This study examined the cardiovascular systems of the inhabitants of the two analyzed territories, in which the prevalence of cardiovascular diseases was used as a health indicator. A qualified cardiologist inspected the inhabitants of both territories. Hemodynamic parameter measurements were performed on the inhabitants, including heart rate, systolic and diastolic blood pressure; mean arterial pressure, and systemic vascular resistance. The electrocardiogram signal was registered in the supine position in a second standard lead. Based on these data, an expert estimated the condition of the cardiovascular system of each inhabitant. Based on these estimated data, the expert then categorized the condition of the cardiovascular system (CCS) for each inhabitant as either CCS=0 (no pathology), or CCS=1 (clear signs of pathology). Simultaneously, we compiled indicators of gender, age and body mass index (BMI) of the residents as well as the presence of weather reactions and sleep disorders. The relationship between these parameters and cardiovascular status of patients was confirmed by a number of studies [10-16].

The research participants included 380 individuals living in the two analyzed territories. The study included only adults aged 18 to 84 years (48.9 ± 16.9). A total of 238 inhabitants (77 men and 161 women), with mean age 50.6 ± 16.7 years, were surveyed in the Techa river basin. Additionally, 142 inhabitants (56 men and 86 women), with mean age 46.0 ± 16.9 years, were surveyed in the control territory. A consent letter was signed by each participant. Research was conducted in accordance with the standards of the Ethics Committee of the Institute of Industrial Ecology of Ural Branch of Russian Academy of Sciences, and with the Helsinki Declaration.

Data analysis was performed using logistic regression and a test to compare the two proportions [17]. Mean values, standard errors, and level of significance of the differences were calculated using descriptive statistical methods. The confounding variables were assessed using logistic regression. The statistical significance level was set at 0.05.

RESULTS

Table 1 shows the prevalence of cardiovascular diseases and covariates in the case and control groups. According to these data, the relative risk (RR) of cardiovascular pathology following the radioactive contamination was $RR=W_1/W_0=52.5/32.4=1.62$ (95% confidence interval (CI): 1.24-2.12), with an odds ratio (OR)=2.31 (95% CI: 1.50-3.57). The impact of radioactive contamination is therefore statistically significant, with $p<0.001$.

Table 1 Characteristics of the case and control groups

Groups	W (%)	Male (%)	Age (years)	BMI	Disturbed sleep (%)	Meteosensitivity (%)
0 (Control)	32.4	39.4	46	26	32.4	32.4
1 (Case)	52.5	32.4	50.6	26.3	45.4	57.6
p value	<0.001	0.17	0.01	0.59	0.01	<0.001

The difference in the percentage of men in the control group (39.4% and 60.6 of women) versus the case group (32.4%) was statistically insignificant (p=0.17, based on a two proportions test [18]). The difference in mean BMI was also insignificant (p=0.59). However, a significant difference between the case and control groups was found for age (the residents of the case territory were older than those in the control territory). The prevalence of sleep disorders and meteotropic reactions was significantly higher in the case group than that in the control group.

Thus, covariates of age, disturbed sleep and meteosensitivity (negative reaction of the organism to environmental changes in meteorological and heliogeophysical factors), which are unequally distributed in the studied groups, may be confounding factors that distort the true impact of the radioactive contamination on the prevalence of cardiovascular pathologies. To test this hypothesis, we needed to determine whether these covariates affect the prevalence of cardiovascular pathologies. In cases where the effect is present, these factors should be considered confounding factors, and an adjustment of the W_0 and W_1 values should be performed.

Table 2 shows the relationship between the prevalence of cardiovascular pathologies and the confounding factors given in Table 1. For a more detailed analysis, the assessment of these relationships was performed separately for the control and case groups, with the following conclusions: (i) compared with the case group, gender affects the prevalence of cardiovascular pathology more in the control group (control: OR=2.06 (90% CI: 1.09-3.89); case: OR=1.41 (95% CI: 0.81-2.43)); (ii) the other analyzed indicators have a greater impact on the prevalence of cardiovascular pathology in the case group than that in the control group, especially disturbed sleep.

Table 2 The effects of confounding factors on the prevalence of cardiovascular diseases

Factors	Control group		Case group	
	OR (95% CI)	p value	OR (95% CI)	p value
Gender	2.06 (0.96-4.42)	0.06	1.41 (0.81-2.43)	0.22
Age	1.08 (1.05-1.12) *	<0.001	1.11 (1.08-1.14) *	<0.001
BMI	1.12 (1.04-1.20) *	0.002	1.25 (1.17-1.34) *	<0.001
Disturbed sleep	6.74 (3.06-14.85)	<0.001	12.23 (6.51-22.97)	<0.001
Meteosensitivity	5.76 (2.64-12.55)	<0.001	8.22 (4.55-14.85)	<0.001
*The odds ratio for age and BMI (body mass index) calculated per unit of measurement (age shown as years; BMI shown as conventional units)				

Thus, the factors age, disturbed sleep and meteosensitivity, which significantly affect the prevalence of cardiovascular pathology and are unequally distributed in the control and case groups, act as confounding factors [6]. An adjustment of the studied effect RR=W_1/W_0 on the confounding factors was performed with logistic regression [19] using an approach that we previously proposed [20]. According to our previous work, we should construct multiple logistic regression equations for all studied residents of the case and control territories to account for confounding variables (the predictors X are the covariates from Table 1). Then, we should calculate the probability W_0 and W_1 for the mean values of the X covariates, which are identical for the case and control groups. For X, we selected the percentages or average values of covariates for all studied residents without dividing the studied population into the case and the control (these are the values recommended by the World Health Organization [6]).

The probabilities (W) for the case and control groups were then calculated according to the following formula [19]:

$$W_{adj} = \frac{\exp(b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5)}{1 + \exp(b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5)}. \quad (1)$$

The list of predictor xi and bi coefficients is given in Table 3. As shown above, the factors age, sleep disorders and meteosensitivity are the true confounding factors. We have also included the covariates gender and BMI in equation (1) because they can act together as confounding factors.

Table 3 Average values of the confounders X and the coefficients b_i of multiple logistic models for the case and control territories

Factors (notation in equation (1))	Mean values of X (groups 0 and 1 together)	Coefficients of the logistic regression model (1)	Control		Case	
			coefficients	p value	coefficients	p value
The free term of the equation	-	b_0	– 6.837	<0.001	– 9.732	<0.001
Male sex (x_1)	35.00%	b_1	0.352×10^{-3}	0.94	$2.62 \cdot 10^{-3}$	0.53
Age (x_2)	48.9 years	b_2	0.0678	<0.001	0.0829	<0.001
BMI (x_3)	26.2 units	b_3	0.0807	0.06	0.153	<0.001
Sleep disorders (x_4)	40.50%	b_4	0.531×10^{-2}	0.31	1.169×10^{-2}	0.005
Meteosensitivity (x_5)	48.20%	b_5	0.846×10^{-2}	0.1	1.676×10^{-2}	<0.001

The results of calculations from formula (1) using the data from Table 3 are as follows:

- The adjusted (after control for confounding factors) prevalence of cardiovascular pathology in the control group was practically unchanged: $W_{0,\ adj}$=31.5%.
- The adjusted prevalence of cardiovascular pathology in the case group $W_{1,\ adj}$=42.1% was significantly decreased relative to the prevalence before adjustment W_1=52.5%.

The reason for reducing the value W is clear. According to Tables 1 and 2, the confounding factors are more common and have the greatest impact on the prevalence of cardiovascular pathology (W) in the control group. For example, the average age of the studied residents in the control group was lower than that in the case group, and this may also affect the prevalence of cardiovascular pathology in these groups. As a result, the relative risk of cardiovascular pathology caused by the radioactive contamination of the territory was reduced to $RR_{adj} = W_{1,\ adj}/W_{0,\ adj}$=1.34 (95% CI: 1.02-1.76), p=0.04. The odds ratio decreased to 1.58 (95% CI: 1.03-2.41). Thus, the impact of the radioactive contamination of the territory on the prevalence of cardiovascular diseases remains statistically significant (p=0.02).

Finally, we assessed the impact of radioactive contamination of the territory on the prevalence of cardiovascular pathology in the allocated populations. We assessed the impact separately for women and men. Likewise, we assessed the impact separately for the young and the elderly (by dividing the samples based on median age under 52 years and over 52 years). We also divided the sample into persons with a normal weight (BMI<25) and persons who were overweight or obese (BMI ≥ 25).

Finally, we divided the sample into persons with sleep disorders and weather-sensitivity compared with those without sleep disorders and meteotropic reactions (Table 4). Table 4 shows that the radioactive contamination of the territory has a greater negative impact on men than on women, on the elderly than on the young, on people with higher BMI values than those with normal BMI values, on individuals with sleep disorders compared with individuals without sleep disorders, and on persons with meteotropic reactions compared to those without meteotropic reactions. Thus, no statistically significant effect of radioactive contamination was found for residents younger than 52 years, residents with a normal body weight, residents without sleep disorders, and residents without meteotropic reactions. However, the impact of radioactive contamination on the elderly, on those with elevated body weight, and on those with sleep disorders was highly significant. Indeed, for all of these groups, the level of statistical significance, p<0.01. The impact of the radioactive contamination of the territory on the subjects with meteotropic reactions was also statistically significant (p=0.05), although at a lower significance level.

Table 4 The effect of radioactive contamination on the selected groups

Factors	Levels of covariates	OR (95% CI)	p value
Gender	Women	1.99 (1.16-3.40)	0.012
	Men	2.90 (1.34-6.29)	<0.001
Age	<52 years	1.95 (0.840-4.56)	0.12
	≥52 years	2.50 (1.28-4.88)	<0.007
BMI	<25	1.67 (0.84-3.31)	0.14
	≥25	3.12 (1.77-5.95)	<0.001
Sleep disorders	no	1.66 (0.87-3.16)	0.12
	yes	3.01 (1.38-6.56)	0.005
Meteosensitivity	weather-resistant persons	1.33 (0.68-2.63)	0.4
	weather-sensitive persons	1.98 (1.02-3.92)	0.05

DISCUSSION

The impact of radioactive contamination on the prevalence of cardiovascular pathologies (W), detected by comparing the W values between the case and control territories, is distorted by confounding factors. Indeed, as shown in Table 1, the residents of the control territory were younger and less susceptible to sleep disturbances and meteotropic reactions. The differences between the residents of the case and control territories can significantly change the W value and distort the effects of radioactive contamination on the territory. Among the considered confounding factors affecting the prevalence of cardiovascular disease, we included the traditional risk factors for cardiovascular disease defined by the World Health Organization (gender, age, BMI). The last of these is a modifiable trait (an individual has the ability to change it). The significance of other confounders (sleep disorders and meteosensitivity) was confirmed by an analysis of our data.

The impact of traditional risk factors such as a male gender, belonging to an older age group [16] and an increased BMI [11] on higher risk of cardiovascular diseases are well known, and our results confirm the same. Our data indicate that radioactive pollution of the territory has increased the impact of risk factors such as age and BMI (Table 2).

Accounting for the confounder such as sleep disorders shows one of the highest OR values for the prevalence of cardiovascular pathology, suggesting the importance of this risk factor (Tables 3 and 4). However, the mechanism of interaction between sleep disorders and risk of cardiovascular diseases is not yet understood [13]. There is evidence suggesting that sleep disturbances affect the occurrence of cardiovascular diseases [13], but this interrelation can also be attributed to the increasing influence of covariates [14,21]. Furthermore, an inverse relationship is possible, in which the sleep disorders are the secondary manifestations of the disease, including cardiovascular disease [10].

According to Tables 2 and 4, meteosensitivity is a significant risk factor for cardiovascular diseases. The vulnerable groups in terms of meteosensitivity include the elderly and persons with cardiovascular pathologies and other chronic diseases. The mechanism of meteosensitivity can be explained by an increase in autonomic nervous system load arising from meteo-geophysical changes [15]. However, this can also be explained by the presence of an insufficient adaptation reserve (for example, due to illness, age, or stress), which can cause increased stress on the autonomic nervous system and induce a disadaptation (such as the exacerbation of cardiovascular diseases). Thus, a link between meteosensitivity and the development of cardiovascular diseases can be observed, which is manifested in the strengthening of pathological reactions to changes in meteorological and heliogeo-physical factors depending on the stage of cardiovascular diseases.

CONCLUSION

We found that radioactive contamination within the Ural region had a statistically significant influence on the prevalence of pathologies of the cardiovascular system (OR=2.31, 95% CI: 1.50-3.57, p<0.001). After accounting for confounding factors, the odds ratio for radiation impact on the prevalence of pathologies of the cardiovascular system decreased to 1.58 (95% CI: 1.03-2.41, p=0.02). By analyzing the combination of radioactive contaminates and confounding factors, we found that the effect of radiation on the prevalence of cardiovascular diseases was different for the different levels of the confounding factors. Hence, the effect of radiation is different for men than for women, for young than for old, etc. A statistically significant increase in the prevalence of cardiovascular diseases in the contaminated territories compared with the control territories was revealed in the presence of the confounding factors older age, overweight, sleep disorders and meteosensitivity.

DECLARATIONS

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Conflict of Interest

The authors and planners have disclosed no potential conflicts of interest, financial or otherwise.

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