Background ionizing radiation and semen parameters of men with reproductive problems

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Wdowiak A, Stec M, Raczkiewicz D, Bień A, Iwanowicz-Palus G, Panasiuk L. Background ionizing radiation and semen parameters of men with reproductive problems. Ann Agric Environ Med. 2020; 27(1): 43–48. DOI: 10.26444/aaem/118155

Abstract

Introduction and objective. The male reproductive system constitutes a set of tissues which are particularly sensitive to external factors. The aim of the study was to analyze the relationship between background radioactivity and the quality of the semen of the men who have reported to the infertility treatment facility in 2000–2016 in the Lublin region of eastern Poland.

Materials and method. The radioactivity of the ground-level air layer obtained from the Institute of Meteorology and Water Management in Włodawa in the Lublin region was analysed. 4,250 spermiograms of patients who reported to the treatment facility for the first time due to infertility were analysed and correlated to background radioactivity in the Lublin region in 2000–2016.

Results. A long-term decrease in the percentage of morphologically normal spermatozoa of the patients was observed (r=-0.970; p<0.001 in 2000–2009 and r=-0.925; p=0.003 in 2010–2016). Men’s age correlated negatively with sperm motility (r=-0.164; p<0.009) and morphology (r=-0.186; p<0.009). The percentage of spermatozoa with normal morphology was lowered by beta-isotopes of artificial origin in the air in 2000–2009 (r=-0.655; p=0.040) and by the exposure to gamma radiation of the ground-level atmosphere in 2010–2016 (r=-0.676; p<0.048). The percentage of sperm vitality was lowered by gamma radiation in the atmosphere (r=-0.636; p=0.006), but improved by beta isotopes in precipitation (r=0.686; p=0.002) in the whole of the analyzed period.

Conclusions. The percentage of morphologically normal spermatozoa in patients who reported to the infertility treatment depends not only on the age of patient, but also on beta-isotopes of artificial origin and gamma radiation in the atmosphere. Beta isotopes in precipitation affect the improvement of sperm vitality.

Key words

ionizing radiation, men, semen analysis, sperm quality, reproduction, male infertility

INTRODUCTION

Radioactivity is an inseparable element of our lives and the environment. In the environment we deal with radioactive isotopes of both natural and artificial origin caused by human activities. Natural radioactivity originates from radioactive isotopes triggered by the actions of cosmic rays directed on the nuclei of nitrogen, oxygen and argon atoms present in the atmosphere. Natural radioisotopes are also to be found in the soil and the earth’s crust [1].

The intensity of the radioactive radiation on earth has been changing over thousands of years. The level of radioactive activity also varies depending on the geographical location. Changes in the intensity of the radioactive radiation in the past have influenced the physiology, mutation and selection of organisms that live on earth [1, 2]. These processes are in still progress, and the available literature confirms the impact of background radioactivity on human health [3, 4].

The effects exerted by the ionizing radiation on living organisms directly depend both on the size of the dose and the kind of radiation. The biological consequences derive from the radiation conditions, such as the strength of the dose, way of fractioning, mass and type of tissues exposed to radiation, as well as their oxygenation. The effects of the exposure to radioactivity depends also on the individual biological characteristics of a body [5–8].

According to one theory, even small doses of radioactive radiation can have a beneficial effect on the functioning of living organisms. This phenomenon has been described as the hormetic effect [7, 9–11]. Undoubtedly, large doses of radiation have a negative impact on the physiology of the body. The basic pathomechanism of cell damage caused by the influence of ionizing radiation is the formation of free radicals. Oxidative stress is the cause of the damage to the DNA and other macromolecules [12, 13].

The male reproductive system constitutes a set of tissues which are particularly sensitive to external factors. A mature sperm practically does not have any self-repair mechanisms of its own DNA [14]. It can therefore be expected that even small doses of background radioactivity may affect the male reproductive functions.
OBJECTIVE

The aim of the study was to analyze the relationship between the background activity and the quality of semen of men treated for infertility for the first time in 2000–2016 in the Lublin region of eastern Poland.

MATERIALS AND METHOD

Radiation. The radioactivity of the ground-level air layer obtained from the Institute of Meteorology and Water Management in Włodawa in the Lublin region was analysed. The data on radioactivity were carried out using the FHT59Si device in Bq/m² units at the Early Radiation Detection Network Station. The analyzed data on radioactivity were as follows:

- radioactive concentration of alpha isotopes of artificial origin in the air;
- radioactive concentration of beta isotopes of artificial origin in the air;
- radioactive concentration of alpha isotopes of natural origin in the air;
- radioactive concentration of beta isotopes in the total monthly drop;
- value of the exposure dose of gamma radiation.

Study group. Data on semen parameters were analyzed in patients treated for infertility. The patients presented themselves the first time to Independent Public Clinical Hospital No. 1, NZOZ Ovum (Non-Public Health Care Facility) and the Luxmed Medical Centre in the Lublin region in years 2000–2016. The spermograms of the couples with WHO infertility diagnosis were analyzed, and the men were sex and alcohol abstinent for 3–5 day preceding the ejaculation. The exclusion criteria from the study group were: absence of semen in the ejaculate or the number of spermatozoa insufficient to conduct a reliable semen analysis. In total, data on the semen parameters of 4,250 men was obtained, 250 men in each of the 17 analyzed years. The study was approved by the Bioethics Committee of the Medical University in Lublin (Approval No. KE-0254/306/2016).

Semen evaluation. The semen samples from 2000 – 2009 were evaluated according to the WHO 1999 standards, and from 2010 – 2016 according to the WHO 2010 standards. According to WHO 2010 standards concerning sperm motility, only the progressive motility was evaluated. In the WHO 1999 standards, the progressive motility was divided into fast and slow. In order for the study to comply with the WHO 2010 standards, both the fast and slow progressive motility were then summed-up. Due to the modifications related to the WHO 2010 sperm morphology, morphologically normal spermatozoa were analysed separately in two sub-periods – 2000–2009 (according to WHO 1999) and 2010–2016 (according to WHO 2010) [15–17].

Statistical methods. Statistical analysis of the collected data was performed in statistical computer package STATISTICA (StatSoft, Poland). Arithmetic means (M) and standard deviations (SD) were estimated for continuous variables. Time series of radioactivity of the ground-level atmospheric layer, age and male semen parameters were analysed using Person’s correlation coefficients between the levels of studied phenomena and years. In the case of the presence of linear trends, their parameters were estimated using regression models of the studied phenomena, with t explanatory variable representing the number of time series, with estimation of coefficient of determination. Pearson’s correlation coefficient was also used to analyse correlation between age and semen parameters, and between radioactivity and mean semen parameters in 2000–2016. The regression models of semen parameters versus radioactivity of the ground-level atmosphere layer were also estimated. The selection of explanatory variables for the regression models was performed by backward step regression. The significance level of 0.05 was considered to be statistically significant.

RESULTS

Changes in radioactivity of ground-level atmosphere. The concentration of radioactive beta isotopes of artificial origin in the air in 2002–2016 fluctuated from 0.001 – 0.312 Bq/m³, and the alpha isotopes from 0.003 – 0.077 Bq/m³ (Fig. 1). The concentration of the radioactive beta isotopes of artificial origin in the air was generally higher than that of alpha isotopes (except for 2013 and 2014). There were no significant long-term increasing nor decreasing trend in the concentrations of the beta isotopes (r=0.307; p=0.231) and the alpha isotopes (r=0.173; p=0.507).

In the studied years, the concentration of radioactive alpha isotopes of natural origin in the air fluctuated from 3.54 – 10 Bq/m³, without significant increasing nor decreasing trend (r=−0.027; p=0.920). However, the concentration of radioactive beta isotopes in the total monthly fall in the Lublin region had an increasing trend in 2000–2016 (r=0.602; p=0.011). In the first half of the studied period it fluctuated around 6 Bq/m³, while in the second half – around 8 Bq/m³ (Fig. 2).

The strength of the exposure dose of gamma radiation in the Lublin region in 2000–2006 oscillated around 82 nGy/h. In the following years, it gradually decreased to 61.5 nGy/h in 2012, and then increased again to about 80 nGy/h in 2014, and remained at this level until 2016 (Fig. 3).

Changes in age and semen parameters. In 2000–2016, the average age of the men who presented themselves for infertility treatment increased systematically from 30.9 years in 2000 to 33.5 years in 2016, by 0.14 year, on average, from year to year (γ=−0.141±30.75, r²=0.83, r=0.913; p<0.001).
Table 1. Semen parameters in studied males (M±SD)

| Year | Age (years) | Volume of ejaculate (mL) | Total sperm count in ejaculate (mln) | Density of ejaculate (mln sperm/mL ejaculate) | Progressive sperm motility (%) | Morphologically normal spermatooza (%) | Sperm vitality (%) |
|------|-------------|--------------------------|-------------------------------------|-----------------------------------------------|-----------------------------|-------------------------------------|-------------------|
| 2000 | 30.9±4.5    | 3.4±1.6                  | 81.9±81.1                           | 23.9±18.7                                     | 34.5±18.2                   | 54.9±12.3                          | 45.2±15.3         |
| 2001 | 30.7±4.0    | 3.5±1.6                  | 84.6±81.7                           | 25.4±21.7                                     | 37.8±15.8                   | 51.3±12.8                          | 48.2±15.8         |
| 2002 | 31.6±4.8    | 3.4±1.4                  | 86.4±75.8                           | 26.7±21.3                                     | 40.0±16.7                   | 47.3±13.3                          | 57.5±12.8         |
| 2003 | 31.9±4.7    | 3.6±1.3                  | 87.9±78.5                           | 24.9±18.4                                     | 39.9±14.6                   | 43.9±13.7                          | 55.9±14.3         |
| 2004 | 31.3±4.5    | 3.8±1.9                  | 92.7±89.3                           | 24.0±19.9                                     | 36.8±15.9                   | 38.6±13.7                          | 62.0±15.6         |
| 2005 | 31.7±4.7    | 4.1±1.9                  | 111.8±97.4                          | 27.4±20.6                                     | 36.1±15.8                   | 36.5±15.3                          | 59.1±17.8         |
| 2006 | 31.6±4.3    | 4.7±2.3                  | 160.1±149.3                         | 34.7±26.9                                     | 37.2±14.4                   | 32.2±13.2                          | 57.9±15.2         |
| 2007 | 32.1±4.4    | 4.8±2.5                  | 161.8±159.6                         | 35.9±31.9                                     | 36.2±15.9                   | 35.2±11.9                          | 59.6±19.6         |
| 2008 | 32.1±4.4    | 4.2±2.3                  | 178.4±167.6                         | 42.1±30.0                                     | 43.2±14.8                   | 31.4±12.6                          | 63.8±15.7         |
| 2009 | 31.8±4.3    | 4.8±2.4                  | 202.2±169.3                         | 44.5±33.6                                     | 38.3±15.3                   | 25.8±12.0                          | 66.7±18.6         |
| 2010 | 31.8±4.4    | 3.9±1.7                  | 178.6±152.5                         | 48.0±34.7                                     | 37.9±15.5                   | 24.4±14.5                          | 72.2±18.8         |
| 2011 | 32.0±4.4    | 4.5±2.1                  | 144.0±140.1                         | 33.1±26.4                                     | 18.3±11.1                   | 13.0±13.9                          | 73.6±18.2         |
| 2012 | 32.4±4.2    | 4.0±1.9                  | 110.1±101.8                         | 29.9±25.6                                     | 17.9±11.3                   | 10.9±12.6                          | 76.8±15.4         |
| 2013 | 32.8±4.2    | 4.1±2.0                  | 122.4±108.5                         | 30.7±24.0                                     | 36.0±13.6                   | 9.9±13.3                           | 76.8±15.0         |
| 2014 | 33.0±4.5    | 3.8±1.7                  | 111.6±105.7                         | 31.0±27.0                                     | 34.9±12.9                   | 5.6±8.6                            | 76.7±15.1         |
| 2015 | 33.5±5.0    | 4.3±2.1                  | 175.2±151.2                         | 43.3±34.2                                     | 40.3±15.3                   | 3.3±4.9                            | 75.7±13.3         |
| 2016 | 33.5±5.1    | 4.0±1.7                  | 155.8±129.0                         | 40.9±32.1                                     | 39.2±14.9                   | 2.9±5.2                            | 73.6±15.7         |
average percentage of morphologically normal spermatozoa correlated negatively with beta radioactive isotopes in the air of the region in 2000–2009 (r = -0.655; p = 0.040) and the strength of the dose of gamma radiation in this region in 2010–2016 (r = -0.676; p = 0.048).

Regression models of semen parameters versus radioactivity of ground-level atmosphere. In the regression model of the average percentage of viable spermatozoa (Fig. 4, y = 24.94 + 5.36x), the average percentage of the viable sperm were higher, on average, by 5.36 percentage points, with an increase in beta radioactive isotopes in the precipitation by 1 Bq/m². In this regression model, the effect of gamma radiation on the average percentage of the viable spermatozoa was not significant because of significant correlation between the strength of the gamma dose exposure and the beta radioactive isotope concentration (r = -0.86; p = 0.013).

In the regression model of average percentage of morphologically normal spermatozoa in 2000–2009 (Fig. 5, y = 51.83 – 199.27x), the average percentage of morphologically normal spermatozoa, on average, was lower by 2.4 percentage points, with a simultaneous increase in the radioactive beta isotopes of artificial origin in the air by 100 Bq/m³.

In the regression model of the average percentage of morphologically normal spermatozoa in the 2010–2016 (Fig. 6, y = 52.11 – 0.59), the average percentage of morphologically normal spermatozoa was lower, on average, by 0.59 percentage points, with a simultaneous increase in the strength value of the gamma radiation exposure dose by 1 Gy/h in those years.
DISCUSSION

The conducted study indicated that background radiation has a negative influence on the sperm morphology and viability. Until now, studies focusing on the effects of natural background radiation (NBR) on male seed have been published by Premi S. et al, which focused on the genetic material of the sperm. Research by Premi S. et al. analyzed the AZF region using the DNA from blood and semen of 100 males living near the coastal peninsula in Kerala (India), exposed to NBR, along with 50 other normal fertile males. This study proved the presence of the impact of natural background radiation on the human Y chromosome owing to its haploid status and clonal inheritance [18]. Moreover, further research by Premi S. et al. indicated the presence of tandem duplication and copy number polymorphisms of the SRY gene in patients with sex chromosome anomalies, and males exposed to natural background radiation [19]. Both Premi S. et al. and Pathak D. also confirmed the mutagenic effect of NBR on the sperm Y chromosome [20, 21].

Other scientific reports discussing the influence of radiation on the quality of semen address the radioactivity related to the work environment. The study by Kumar et al. among volunteers from various hospital-exposed diagnostic or therapeutic radiation (X/β/γ rays) facilities, demonstrated an adverse effect of the radioactivity on motility characteristics, viability, and morphological abnormalities of the semen, which is in line with the results of the presented research. This study also demonstrated that the workers exposed to radioactive factors presented both a higher level of sperm DNA fragmentation and a significant number of hypermethylated spermatozoa, in comparison to the non-exposed group [22]. Research by Kumar et al., indicated that exposure to radioactivity caused by the work environment leads to disorders in the oxidase-reduction system of the semen, which may explain the pathomechanisms of sperm dysfunction found in our studies [12]. A similar observation concerning the erythrocytes of subjects professionally exposed to radiation have been presented by Klucinski et al [23].

In the current study, the most adverse implications on semen morphology were related to gamma radiation. The harmful effects of this radiation on male sperm were also confirmed by the results of a study by Alvarez R. et al. who indicated that this kind of radiation has effects on the occurrence of sperm DNA damage [24]. Such a negative effect of gamma radiation has likewise been described in an animal model by Saiyad Musthafa M. et al. After irradiation, they observed disorders in the endocrine function of male gonads [25]. Other research by Permi S. et al. and Pathak D. also confirmed the mutagenic effect of NBR on the sperm Y chromosome [20, 21].

In 2000–2016, a long-term increase in the age and a decrease in the average percentages of morphologically normal spermatozoa was observed among men presenting to medical facilities due to their infertility. The men’s age proved to have an adverse effect on sperm motility and morphology. The percentage of sperm with normal morphology was lowered by beta-isotopes of artificial origin present in the air in 2000–2009, as well as by exposure to gamma radiation of the ground-level atmosphere in 2010–2016. During the whole researched period, the increase of beta isotopes in the precipitation associated with the improvement in semen viability.

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