REVIEW ARTICLE

Invisible Waves, Visible Consequences: Environmental Radiation's Role in Human Fertility

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Abstract

Environmental radiation is one of the key causes of the increased prevalence of infertility among couples. This type of radiation can be ionizing or non-ionizing. While ionizing radiation is known to cause sterility in both males and females, the role of low-energy non-ionizing radiation is still debated. This article will discuss the various types of environmental radiation and its consequences on male and female fertility. Recent studies suggest that continuous exposure to low-energy, non-ionizing radiation might also result in infertility. The sources of this type of radiation are generally man-made, including mobile phones, television broadcasts, radio, radars, etc. The ever-increasing use of these devices in our daily lives has introduced a new type of pollution called electropollution. The mechanisms of action by which electropollution causes infertility are still being investigated. In males, prolonged exposure to this type of radiation might negatively impact sperm parameters, such as count, motility, morphology, and viability. The evidence for female infertility caused by non-ionizing radiation is still evolving.

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Introduction

Radiation is energy given off by matter in the form of rays or particles. Since the formation of our planet, Earth, and the evolution of life, radiation has been our constant companion. It is all around us, and we are continuously exposed to it from the cradle to the grave—it is ubiquitous.[1]

While cosmic and natural background radiations have minor effects, man-made radiation sources pose significant health hazards.[2] These low-energy artificial radiations were initially conceived as unharmful to humans; however, recent studies conducted *in vitro* and *in vivo* prove otherwise.[2,3] This is especially important with the increasing use of 5G, Wi-Fi routers, and other connectivity devices.[4] This review article discusses the various types of environmental radiation and their consequences on male and female fertility.

Literature Findings

Radiation

The radiation we are exposed to is categorized as ionizing radiation (IR) and non-ionizing radiation (NIR).[5]

Ionizing Radiation (IR). This type of radiation has enough energy to excite and ionize the matter through which it passes.[5] While passing through matter, IR induces biological effects either directly or indirectly. The direct effect occurs when IR directly disrupts the atomic structure of the matter through which it passes. Indirect effects are linked to the secondary particles (such as free radicals) produced after IR passes through the medium.[5]

Sources of IR. Sources of IR can be natural and man-made.[1]

Natural IR sources include cosmic rays, cosmogenic radionuclides, and terrestrial sources (such as the radionuclides on Earth's crust). The air we breathe and the food and water we ingest also contain trace amounts of radionuclides, making our human body radioactive.[1] Natural exposure to IR in trace amounts from these sources does not cause health hazards in the ordinary course.

Man-made IR sources include nuclear power reactors, equipment used in the healthcare sector, industrial uses of radionuclides, nuclear weapon testing, and radiation accidents. The IR from these sources is linked to infertility, an aspect that has been discussed later in this article.

Non-Ionizing Radiation (NIR). As the name suggests, this type of radiation cannot ionize atoms through which it passes—that means it cannot knock off the electron

from the orbit of an atom. Instead, it has sufficient energy only to excite an atom—that is, to move the electron to a higher energy level without removing it from the orbit.[5] This excitation produces charged ions, that can produce adverse biological effects, including infertility.

Sources of NIR. Similar to IR, NIR can be obtained from natural or man-made sources.[6] Sunlight, lightning discharges, etc., are the natural sources of NIR. Man-made sources of NIR include wireless communications (such as mobile phones, television broadcasts, radio, radars, etc.), various industrial and scientific applications, and specific medical applications.

NIR, a part of the electromagnetic field (EMF) spectrum, is further classified into four approximate regions based on frequency.[7] (i) Static electric and magnetic fields (MRI, Geomagnetism): 0 Hz. (ii) Extremely low-frequency fields (military equipment, Railroads): 0 Hz to 300 Hz. (iii) Intermediate frequency fields (televisions, industrial cables, computer monitors): 300 Hz to 10 MHz. (iv) Hyper frequency fields (mobile phones, radio), 10 MHz to 3000 GHz.

Although there are many different environmental radiations to which humans are exposed, the biological effects of radiofrequency-electromagnetic field (RF-EMF) radiations have been extensively studied. The frequency of this radiation ranges between 100 kHz and 300 GHz (intermediate and hyper-frequency range). They are contributed by routinely used daily equipment, such as cell phones, cell phone towers, radars, Wi-Fi, laptops, TV broadcasts, radio transmissions, and microwave ovens. The omnipresence of RF-EMF in the environment is now called electropollution or electrosmog.[3] The inability of humans to sense electropollution makes it even more dangerous.

Standards and Guidelines for NIR. Considering the potential dangers of this type of pollution, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the World Health Organization (WHO) developed international guidelines to limit NIR exposure to the general public. Specific Absorption Rate (SAR) is one of the parameters in which mobile phones' exposure limits have been defined. SAR measures the rate at which energy is absorbed by a unit mass of tissue in an electromagnetic field. The unit of measurement of SAR is watts per kilogram (W/kg). Internationally, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) legally limits SAR for mobile phones to 2.0 W/kg.[8] However, the accepted value of SAR values varies in different nations. The SAR limit in India was 2.0 W/kg until 31 August 2013, but it was lowered to 1.6 W/kg from 1 September 2013.[9] Only mobile handsets conforming to this revised SAR value are permitted to be manufactured or imported into India.

Effect of Radiation on Male Fertility

As discussed above, radiation can be IR and NIR. While IR has a profound effect on male fertility, NIR is not devoid of any impact on spermatogenesis.

Effects of IR. The most common way testicles are exposed to IR is when a patient gets radiotherapy for cancer located in the pelvic region. Even though there are many methods nowadays to reduce testicular radiation to practically negligible doses, in some cases, it becomes challenging.

The radiation effect will not be immediately apparent as post-spermatogonial cells are relatively more resistant than sensitive stem cells.[10] After exposure to a moderate IR level, a man remains fertile for a brief while until all the post-spermatogonial cells are used up. This latent period can last up to 6 weeks.

After the above-mentioned latent period, a radiation dose as low as 0.15 Gy can cause oligospermia. Any dose above 0.5 Gy can cause azoospermia; however, this is only temporary and dose-dependent.[10] If the dose received is between 0.5 Gy and 1 Gy, the infertility might last for approximately a year. If the radiation dose to testicles is above 2 Gy, the exposed individual might need 2 to 3.5 years to recover.

IR can cause permanent sterility if one receives radiation to a dose of 6 Gy or more in a single fraction. The same effect is seen if testicles are irradiated between 2.5 to 3 Gy in a fractionated regime over 2 to 4 weeks.[10]

Effects of NIR. The effects of NIR on fertility are less damaging than IR. As the name suggests, the non-ionizing radiation does not directly ionize the chemical bonds between DNA and cause damage. Instead, it causes damage through other modes of action.

In an experiment by Agarwal *et al.*, the researchers exposed the semen samples to cellular phone radiation, to study its impact on sperm parameters. The semen samples were collected after 48 to 72 hours of abstinence, and after liquefaction, they were divided into two aliquots. One group was kept as a control without cellular phone radiation. The experimental group was exposed to cellular phone radiation in talk mode by holding the specimen 2.5 cm from the phone antenna for 60 minutes. After an incubation period, the mean motility was found to be 48.62 ± 17.36% in the exposed sample and 52.11 ± 18.34% in the unexposed group ($P = .003$). Similarly, sperm viability was lower in the exposed versus unexposed samples (52.33 ± 13.21% and 58.97 ± 14.81% respectively, $P < .001$).[11]

As mentioned above, it is the RF-EMF radiation that causes biological effects in humans.3 Prolonged exposure to this type of radiation might negatively impact sperm parameters such as count, motility, morphology, and viability.[11-14] This impact on sperm parameters can be due to direct radiation received by testicles or indirectly caused by radiation to the pituitary gland.

The indirect effect occurs when the anterior pituitary gland receives extended periods of radiation. It affects the secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH). Consequently, Leydig cells secrete less testosterone, and altered spermatogenesis occurs in seminiferous tubules.[15,16]

On the other hand, radiation that falls directly on testicles causes the accumulation of free radicals, such as

reactive oxygen species (ROS) in the organ. ROS build-up leads to increased consumption of antioxidant enzymes, such as superoxide dismutase, glutathione peroxidase, and catalase. As a result, an imbalance occurs in the system due to the accumulation of free radical molecules, leading to oxidative stress. Consequently, DNA fragmentation occurs, and cells and tissues get biologically damaged.[17-21]

Other reasons for low semen quality in men due to radiation are as follows: (i) increased apoptosis of spermatogenic cells;[22-25] (ii) dysregulation of protein kinases,[26,27] histone kinases,[28] and creatinine kinases[29]; (iii) micronuclei formation[30] and chromosomal damages causing genomic instability, and (iv) sperm mitochondrial dysfunction[17] and disruption of microtubule formation[31] in the sperm tail, leading to decreased sperm mobility.[17]

Effects of radiation on female fertility

Unlike males, females have different gonadal kinetics. All cells progress to the oocyte stage within three days after birth, and no further cell division occurs. As a result, there are fewer actively dividing oocytes for radiation to affect than actively dividing spermatogenic cells among males.[10] Nevertheless, IR can cause permanent ovarian failure.

Effects of IR. Permanent sterility caused by IR is age and dose-dependent – 12 Gy for prepubertal girls and 2 Gy for premenopausal women.[10] Radiation-induced ovarian failure results in hormonal changes similar to those seen in menopause.

Accidental radiation exposure is not uncommon among healthcare staff while performing diagnostic radiology tests with X-rays. The maximum permissible dose to the fetus should not exceed 0.5 mSv per month.[32] So, to stay within this allowable limit, the institute's radiation safety officer should carefully consider a pregnant radiation worker's duties.

The effect of radiation on pregnancy is well documented in the literature. These data mainly arise from Japanese atomic bomb survivors and patients who underwent obstetric X-ray examinations in the past.[32] Radiation exposure during the pre-implantation period causes the potential death of the embryo. In the first trimester, during organogenesis, radiation exposure causes severe growth retardation and severe anomalies in many organs. In the second trimester, radiation exposure causes microcephaly, mental retardation, stunted growth, and organ anomalies. However, exposure in the third trimester of pregnancy has little effect on the infant's structural integrity, but these babies will have a 40% increased risk of developing malignancies in childhood.[32]

Effects of NIR. The evidence for female infertility due to NIR is still evolving. Only a few animal studies[33] and retrospective observational studies point out that NIR could cause sterility in females. Some possible mechanisms of action that could lead to this are as follows: (i) Studies on mice suggest that RF-EMF radiation could prevent the development of antral follicles, inhibit ovulation, and decrease the number of corpora lutea.[34,35]; (ii) Studies indicate that this radiation might increase free radicals' lifespan, causing oxidative stress, DNA damage, and increased apoptosis.[7,36]; (iii) With the evidence of an increased number of macrophages seen in growing follicles and corpora lutea of rats, it is postulated that exposure to NIR might expedite apoptosis in ovarian cortical tissue, leading to oocyte degeneration.[37]; (iv) An observational study done on pregnant women working at a video display terminal noted a higher rate of abortions and congenital disabilities.[38,39]

One should carefully consider these observations because studies on different animal models have shown controversial outcomes.[40]

Protective measures of radiation exposure

Data suggests that treatment with potent antioxidants such as melatonin, *N*-acetyl-cysteine, and green tea extracts can help cells mitigate the effects of radiation and perhaps reverse its effects.[3] Melatonin reduces oxidative stress by detoxifying ROS and stimulating antioxidant enzymes. In another study, melatonin was found to reverse the effects of RF-EMF radiation on sperm count, DNA fragmentation, and testosterone levels.[41-45] Similar to melatonin, green tea extract is also found to be a potent antioxidant. Apart from reducing oxidative stress, it can reduce micronuclei formation in mice exposed to cell phone radiation.[46-49]

Clinicians have adopted different strategies for males and females to reduce the effects of IR during radiotherapy treatment. The most important of these is gonadal shielding while delivering radiotherapy. Along with shielding, using highly conformal radiotherapy techniques available these days can reduce the doses received by gonads to acceptable levels. Other fertility preservation techniques are sperm banking, oophoropexy before radiation treatment, and cryopreservation of oocyte, ovarian tissue, or embryo.[7]

Using lead aprons and wearing personal thermoluminescent devices (TLD) to monitor radiation doses while performing diagnostic X-ray tests can reduce the hazard of occupational radiation exposure.[50]

Although there are various ways to mitigate the effects and lower the exposure, the best way is to avoid it. However, the conveniences of mobile phones, Wi-Fi, and other devices have become integral to modern life, making their complete avoidance nearly impossible. One cannot fathom a world without these devices. In this context, it is crucial to weigh the risks against the benefits of these technologies. Recognizing and managing the implications of electropollution is essential, as it helps ensure that technological advancements do not compromise human health.

Conclusion

One of the reasons for the increased prevalence of infertility among couples is environmental radiation. More studies need to be done to understand further the mechanism of actions involved in causing infertility. Based on these studies, the authorities should enforce stringent guidelines to decrease electropollution and reduce health hazards.

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