Chapter 21

Radiation applications on the male reproductive system

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Abstract

The use of technological devices, which are becoming widespread today, is increasing day by day and the daily exposure rate of the radiation they emit is increasing accordingly. Considering the increase in ionizing radiation (IR) exposure originating from artificial sources such as medical practices and occupational exposure, it is necessary to systematically evaluate the current knowledge on the effects on the male reproductive system in reproductive age and in occupations that are professionally active and have high exposure to IR (medicine, oncological radiotherapy, mining, aviation, etc.). Considering the many studies conducted as a result of this exposure, it is seen that it poses a great threat to human health and also many studies have been conducted on the male reproductive system and it shows that it causes infertility, decreased sperm motility and a decrease in the percentage of morphologically healthy sperm cells in men, causes DNA damage and increases the risk of chromosomal anomalies, which can potentially lead to genetic disorders in subsequent generations.

1. Radiation

Radiation can be defined as "energy coming from a source and passing through a substance or space". It can be divided into two categories: ionizing and non-ionizing (Groen, & Lim, 2012).

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1.1. Non-ionizing Radiation (NIR)

Non-ionizing radiation has enough energy to cause the atoms in a molecule to move or vibrate around, but is not strong enough to knock electrons out of their place (Groen, & Lim, 2012). Extremely low frequency NIR has wavelengths of one million meters or longer and frequencies of 100 Hertz per second or less (Zakariya, & Kahn, 2014). Microwaves and ultrasound waves are examples of these types of radiation; It is also used in medical applications such as magnetic resonance imaging (MRI). NIR forms are widely available in our daily lives. Ultrasound waves and are frequently preferred technologies in medical examinations (Mu et al. 2018).

1.2. Ionizing Radiation (IR)

Ionizing radiation is defined as radiation with sufficient energy to ionize (or remove electrons from) atoms or molecules as it travels through matter. Ionizing radiation from natural sources, including radon gas, has always been a part of life on Earth (McLean et al. 2017). There are four main types of IR: alpha, beta, gamma, and x-rays (Shapiro, 2002). High-energy electromagnetic radiation, such as X-rays and γ-rays, have the power to break chemical bonds in substances they come into contact with. Although this type of ionizing radiation has harmful effects on living things, X- and γ-rays are widely used in the diagnosis and treatment of diseases (Cho et al. 2015). Ionizing radiation is the high energy generated by the spontaneous breakdown of atoms, which is known as radioactivity. People can be exposed to natural sources such as soil, water, and plants, as well as man-made sources of ionizing radiation such as X-rays and medical devices. These sources may originate from cosmic and ground-based radiation, natural background radiation like radon and thoron, or man-made radiation sources like X-rays and nuclear medicine (NM) treatments. Ionizing radiation can be harmful to health if not utilized appropriately or under control, despite the fact that it has numerous useful uses in business, research, agriculture, and medicine (Zakariya, & Kahn, 2014; Chen, 2014). Stochastic effects are effects that can occur even at very low doses, regardless of the dose received, and when or how they will develop is unpredictable. In contrast, deterministic effects occur suddenly as a result of high-dose exposure and can cause serious damage to the organism. Ionizing radiation can cause many undesirable effects, depending on the dose received and the frequency of exposure, which can be deterministic (death, skin burns, cataracts, infertility, etc.) or stochastic (cancer, genetic changes) (Frischknecht et al. 2000; Vandenhove et al. 2018). The severity of biological damage caused by radiation at the cellular level depends on the ionization intensity of the type of radiation.

More intense ionizing radiation causes more ionization in cells, increasing the level of damage (Yavaş, & Çelik, 2019).

2. Ionizing Radiation's Impact on Male Reproductive Health

Changes in the physical, chemical, and psychological settings can have an impact on reproductive function (Younglai et al. 2005). The kind and dose of ionizing radiation have a direct impact on how living things react to it. The irradiation settings, including dose rate, dose fractionation technique, mass and type of exposed tissues, and oxygenation state, also affect these biological consequences. The specific biological traits of the organism also have an impact on the effects of radiation exposure (Wdowiak et al. 2019). There are epidemiological studies (radioactivity, X-ray exposures) examining the effects of low radiation doses on male reproduction. In men exposed to radioactivity, decreased sperm motility, increased percentage of abnormal sperm (especially abnormalities seen in the head region), and increased sperm vacuolization have been found. Ionizing radiation and specific environmental conditions can affect sperm function. When diagnosing male infertility, sperm morphology, motility, and concentration are crucial factors (Santiso et al. 2012; Guzick et al. 2001). Additionally, when the genetic material in the sperm of these men was examined, it was found that fragmentation in genomic DNA increased and total methylation levels intensified (Kumar et al. 2013). Exposure to ionizing radiation causes breaks in the DNA chain that accumulate over a long period of time. This, combined with harmful environmental factors, leads to increased genetic instability in organisms and an increased risk of cancer (Mikhailenko, & Muzalov, 2013). Similar DNA damage and increased pathological forms have been found in the sperm of men involved in the cleanup efforts following the nuclear reactor explosion at Chernobyl. Some research indicates that among survivors of Hiroshima and Chernobyl and those exposed to contaminated buildings, low and medium levels of radiation are linked to infertility, especially in women (and to a lesser extent in men) (Zhou et al. 2016; Sakata et al. 2011). Because sperm and eggs with abnormal DNA can continue to fertilize and pass this abnormal DNA to the zygote through germline mutations, unrepaired DNA damage, epigenetic damage, and protein damage, both mothers and fathers carry a complex body burden that has accumulated over time during the reproductive period (Chapin et al. 2004). Figure 1 shows how germ cells are affected by radiation exposure (Latini et al. 2012). The health of the kids may suffer from birth abnormalities, low or high birth weight, cancer in early life, and chronic disorders in adulthood as a result of contaminated sperm and eggs. Furthermore, infertility may result from these DNA alterations (Aitken et al. 2004).

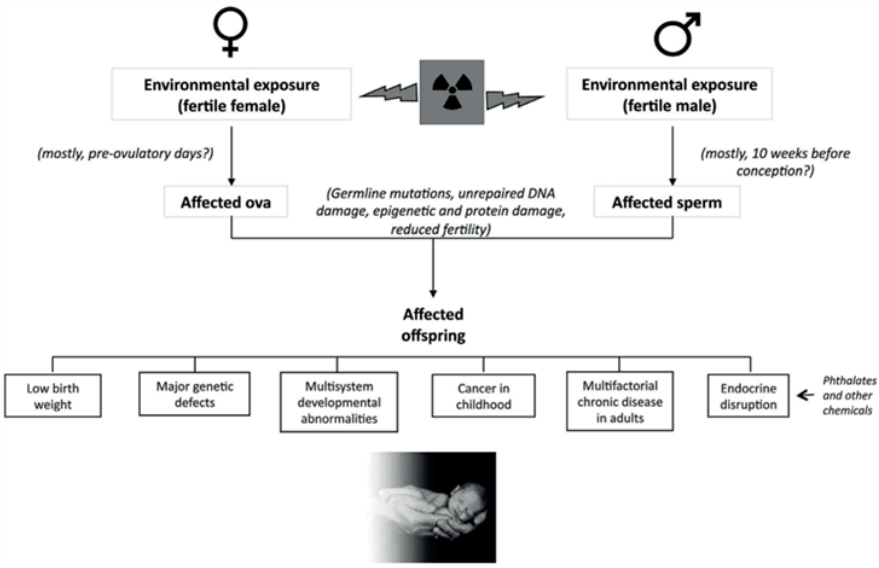

Figure 1: Schematic representation of the effect of ionizing radiation on the male and female reproductive systems (Latini et al. 2012).

Clifton et al. reported that in a study conducted in healthy inmates, a significant dose-related effect of X-rays on sperm production was detected in a combined and sham-menopausal population, and that the effects of irradiation on spermatogonia in mice paralleled those in humans; these results showed great consistency in both sperm production and testicular histology, that in general, human spermatogonia were determined to be 3.1 times more sensitive than mouse spermatogonia (Clifton, & Bremner, 1983). Chater et al. reported in a study that ionizing radiation induces apoptosis in germ cells in the testes (Chater et al. 2007). DNA obtained from blood and semen samples of 100 men was analyzed in the study, which included 50 men of reproductive age who were exposed to high concentrations of natural background radiation (NBR) and lived in an area with thorium-containing monazite sand. The study confirmed the effects of NBR on the human Y chromosome due to its haploid structure and clonal inheritance (Premi et al. 2007). Additionally, Premi et al demonstrated that tandem duplication and copy number polymorphism occurred in the SRY gene in patients with sex chromosome abnormalities and in men exposed to natural background radiation (NBR) (Premi et al. 2006). Kumar et al. conducted a study on volunteers who were occupationally exposed to radiation and worked in facilities where diagnostic or therapeutic radiation (X/β/γ rays) was used in various hospitals, and showed that radioactivity had adverse effects

on sperm motility, vitality and morphological abnormalities (Kumar et al. 2014). In their investigation on an animal model, Musthafa et al. showed the detrimental effects of gamma radiation and noted abnormalities in the endocrine activities of fish male gonads following irradiation (Musthafa et al. 2014). Additionally, a study in another animal model found that exposure of Panstrongylus megistus beetles to gamma radioactivity resulted in reduced reproduction (Verçosa et al. 1993). Azoospermia, as a result of exposure to ionizing radiation, is definitely induced by irradiation of the testicles at high doses such as 6000 mGy (milligray). This condition is observed transiently at a lower dose of 300 mGy. Irradiation of the testicles at 100 mGy causes a decrease in the concentration of both spermatozoa and spermatogonia by approximately 50%. The germ cells of male fetuses in particular are extremely sensitive to ionizing radiation and can be damaged even at low doses of 0.1-0.2 Gy. This suggests that radiation can cause DNA damage and cell death in germ cells (Lambrot et al. 2007).

Conclusion and Recommendation

The effects of ionizing radiation on the male reproductive system are alarming due to both genetic and biological consequences of radiation. Various studies show that exposure to this type of radiation has negative effects especially on the testicles and sperm quality. Ionizing radiation can directly damage the germ cells in the testicles. This can lead to a decrease or cessation of sperm production. Even at low doses, continuous exposure can cause damage to accumulate in the testicular tissue. This damage can lead to genetic disorders in cell division, disrupt sperm morphology and cause infertility. Studies have shown that IR radiation causes breaks and mutations in sperm DNA. Such damage can affect sperm motility and fertilization ability. In addition, the risk of chromosomal abnormalities can increase, which can potentially lead to genetic disorders in subsequent generations and expose new generations to many diseases. The effects of chronic exposure at low doses can appear after many years. Especially in people working in fields such as radiology, reproductive health problems can accumulate over time and effects can be seen after many years. Limiting the time exposed to radiation and using protective equipment (lead aprons, special screens, etc.) can reduce harmful effects. It is necessary to constantly monitor radiation levels in work areas and minimize even low doses. The effects of ionizing radiation on reproductive health vary, especially depending on the duration and dose of exposure. In order to protect men from such effects, work safety standards must be followed and regular health checks must be performed.

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