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BIOLOGICAL EFFECTS OF IONIZING RADIATIONS

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ABSTRACT

The harmful effects of ionizing radiation are very well documented. We cannot completely avoid the harmful effects of radiation however, while working in radiation area we can minimize the amount of radiation received by taking proper safety measure. The purpose of this paper is to review the various biological effects of radiation on human beings. Health care professional who uses ionizing radiation are concerned about the possible acute and chronic effects of occupational radiation exposure. One should have a clear understanding of biological effects of radiation so that proper care should be taken to avoid unnecessary exposure. The biological effect of ionizing radiation is a consequence of the energy transfer by ionization and excitation to body cells. Therefore, there is need to know the various biological effects of radiation on human beings so that we can use radiation safely.

Natural populations have always been exposed to background levels of ionizing radiation. However, with the event of the nuclear age, studies about the effects of higher-than-background levels of ionizing radiation on individuals or populations of organisms became important. Background ionizing radiation arises from various manmade and natural sources present in the environment. We may get radiation from medical procedures, consumer products, industrial radiation sources, research activities, etc. Radiation professionals known as radiation worker may get exposure from radiation sources used by them for various applications3. Most common radiation exposure to the professionals is from various medical procedures used in Radiology, nuclear medicine, radiotherapy, etc.. Worldwide, the mean effective dose for medical workers was 1.6 mSv, and for interventional radiology was 3.0 mSv. In the United States, the mean annual effective dose during 2011 for physicians involved in fluoroscopically was 1.6 mSv. The harmful effects of radiation are very well known to us and while working in radiation area we can only minimize the amount of radiation received but we cannot avoid it completely 5,6. Therefore, there is need to know the various biological effects of radiation on human beings so that we can use radiation safely. Whenever ionizing radiation falls on human body, it produces ionization and excitation in the tissues and impairs the normal function of the cells. Thus human body will be subjected to biological damage and severity of this damage depends upon various factors mainly, nature and energy of the radiation, total dose & dose rate, the extent and part of the body exposed, age of the person exposed to radiation, radiation sensitivity of the organ exposed, etc. The interaction of ionizing radiation with human body could arise either from external radioactive sources or internal contamination leading to biological effects which may later show up as clinical symptoms. Radiobiological data have been derived mostly from micro-organism, cultured mammalian cells and whole animal systems. Human data is derived from the follow-up of the (a) survivors of atomic bomb explosions in Hiroshima and Nagasaki, (b) inhabitants of Marshall islands, who were exposed to fallout from thermonuclear devices, (c) uranium miners, (d) radium dial painters, (e) pioneer X-ray technicians and radiologists, (f) patients exposed to radiation for medical reasons; and (g) victims of nuclear accidents. A careful analysis of these data has yielded reasonable quantitative estimate of biological effects of radiation in man

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INTRODUCTION

The fact that ionizing radiation produces biological damage has been known for many years. The first case of human injury was reported in the literature just a few months following Roentgen's original paper in 1895 announcing the discovery of x-rays. As early as 1902, the first case of x-ray induced cancer was reported in the literature. Early human evidence of harmful effects as a result of exposure to radiation in large amounts existed in the 1920's and 30's, based upon the experience of early radiologists, miners exposed to airborne radioactivity underground, persons working in the radium industry, and other special occupational groups. The long-term biological significance of smaller, repeated doses of radiation, however, was not widely appreciated until relatively recently, and most of our knowledge of the biological effects of radiation has been accumulated since World War. The detrimental effects of ionizing radiation (IR) involve a highly orchestrated series of events that are amplified by endogenous signaling and culminating in oxidative damage to DNA, lipids, proteins, and many metabolites. Despite the global impact of IR, the molecular mechanisms underlying tissue damage reveal that many biomolecules are chemoselectively modified by IR.

The development of high-throughput “omics” technologies for mapping DNA and protein modifications have revolutionized the study of IR effects on biological systems. Studies in cells, tissues, and biological fluids are used to identify molecular features or biomarkers of IR exposure and response and the molecular mechanisms that regulate their expression or synthesis. In this review, chemical mechanisms are described for IR-induced modifications of biomolecules along with methods for their detection. Included with the detection methods are crucial experimental considerations and caveats for their use. Additional factors critical to the cellular response to radiation, including alterations in protein expression, metabolomics, and epigenetic factors, are also discussed. Throughout the review, the synergy of combined “omics” technologies such as genomics and epigenomics, proteomics, and metabolomics is highlighted. These are anticipated to lead to new hypotheses to understand IR effects on biological systems and improve IR-based therapies. [1]

Several biological effects can result from ionizing radiation. These can be due to direct or indirect mechanisms, and they can be acute or delayed. Acute effects occur with exposure to high-level radiation. Delayed effects may appear after a long time and include cancer, genetic effects, effects on the unborn child, and other effects such as cataracts and hypothyroidism. Based on our current knowledge, no level of exposure to radiation can be described as absolutely safe and no level is uniformly dangerous. Radiation doses have to reach a certain level to produce acute injury but not to cause cancer or genetic damage. No biological effects in individuals have ever been documented as being due to levels of ionizing radiation employed for medical diagnosis. Absorbed doses from nuclear medicine procedures are very low. Fear of radiation must not be permitted to undermine the great value of radiation in clinical practice. However, safe handling of all levels of radiation is important to prevent or minimize possible biological effects.

DISCUSSION

Since ionizing radiation damages the DNA, which is critical in cell reproduction, it has its greatest effect on cells that rapidly reproduce, including most types of cancer. Thus, cancer cells are more sensitive to radiation than normal cells and can be killed by it easily. Cancer is characterized by a malfunction of cell reproduction, and can also be caused by ionizing radiation. Without contradiction, ionizing radiation can be both a cure and a cause.[2]

To discuss quantitatively the biological effects of ionizing radiation, we need a radiation dose unit that is directly related to those effects. All effects of radiation are assumed to be directly proportional to the amount of ionization produced in the biological organism. The amount of ionization is in turn proportional to the amount of deposited energy. Therefore, we define a **radiation dose unit** called the *rad*, as 1/100 of a joule of ionizing energy deposited per kilogram of tissue, which is

$$1 \text{ rad} = 0.01 \text{ J/kg}.$$

People are exposed to natural radiation sources as well as human-made sources on a daily basis. Natural radiation comes from many sources including more than 60 naturally-occurring radioactive materials found in soil, water and air. Radon, a naturally-occurring gas, emanates from rock and soil and is the main source of natural radiation. Every day, people inhale and ingest radionuclides from air, food and water.[3]

People are also exposed to natural radiation from cosmic rays, particularly at high altitude. On average, 80% of the annual dose of background radiation that a person receives is due to naturally occurring terrestrial and cosmic radiation sources.

Background radiation levels vary geographically due to geological differences. Exposure in certain areas can be more than 200 times higher than the global average.[4]

Human exposure to radiation also comes from human-made sources ranging from nuclear power generation to medical uses of radiation for diagnosis or treatment. Today, the most common human-made sources of ionizing radiation are medical devices, including X-ray machines.

Radiation exposure may be internal or external, and can be acquired through various exposure pathways.[5]

Internal exposure to ionizing radiation occurs when a radionuclide is inhaled, ingested or otherwise enters into the bloodstream (for example, by injection or through wounds). Internal exposure stops when the radionuclide is eliminated from the body, either spontaneously (such as through excreta) or as a result of a treatment.

External exposure may occur when airborne radioactive material (such as dust, liquid, or aerosols) is deposited on skin or clothes. This type of radioactive material can often be removed from the body by simply washing.[6]

Exposure to ionizing radiation can also result from irradiation from an external source, such as medical radiation exposure from X-rays. External irradiation stops when the radiation source is shielded or when the person moves outside the radiation field.

People can be exposed to ionizing radiation under different circumstances, at home or in public places (public exposures), at their workplaces (occupational exposures), or in a medical setting (as are patients, caregivers, and volunteers).

Exposure to ionizing radiation can be classified into 3 exposure situations. The first, planned exposure situations, result from the deliberate introduction and operation of radiation sources with specific purposes, as is the case with the medical use of radiation for diagnosis or treatment of patients, or the use of radiation in industry or research. The second type of situation, existing exposures, is where exposure to radiation already exists, and a decision on control must be taken – for example, exposure to radon in homes or workplaces or exposure to natural background radiation from the environment. The last type, emergency exposure situations, result from unexpected events requiring prompt response such as nuclear accidents or malicious acts.[7]

Medical use of radiation accounts for 98 % of the population dose contribution from all artificial sources, and represents 20% of the total population exposure. Annually worldwide, more than 3600 million diagnostic radiology examinations are performed, 37 million nuclear medicine procedures are carried out, and 7.5 million radiotherapy treatments are given.

RESULTS

Acute Whole-Body Exposure Syndromes: Following exposure to a large, single, short-term whole-body dose of ionizing radiation, the resulting injury is expressed as a series of clinical symptoms. The sequence of events can be generally divided into four clinical periods:

1. The prodromal period, up to 48 h, when the symptoms include anorexia, nausea, vomiting, and diarrhea
2. The latent period, from 48 h to 2 –3 weeks after exposure, when the patient becomes asymptomatic
3. The manifest phase, from week 6 to week 8 after exposure, when variable symptoms appear based on the radiation dose .

Radiation Sickness: The symptoms can be mild, such as loss of appetite and mild fatigue, or evident only on laboratory tests with mild lymphopenia (subclinical), or may be severe, appearing as early as 5 min after exposure to very high doses of 10 Gy or more and also include fatigue, sweating, fever, apathy, and low blood pressure. Lower doses delay the onset of symptoms and produce less severe symptoms or a subclinical syndrome that can occur with doses of less than 2 Gy to the whole body, and recovery is complete with 100% survival.

Hematopoietic (Bone Marrow) Syndrome: This occurs at higher doses of more than 1.5 –2 Gy to the whole 544 23 Biological Effects of Ionizing Radiation body. With doses up to 4 Gy, a radiation prodrome is seen, followed by a latent period of up to 3 weeks. The clinical effects are not seen for several weeks after the radiation dose, when anemia, petechiae, increased blood pressure, fatigue, ulceration in the mouth, epilation, purpura, and/or infection appear. At doses in the order of 4 –8 Gy, a modified bone marrow syndrome occurs. The initial problem is more severe, the latest period is shortened, and the manifest illness is more severe. Death is possible due to bleeding with exposure in this dose range. [8]

Gastrointestinal Syndrome: This syndrome occurs with still higher doses of 6 –10 Gy which cause manifestations related to the gastrointestinal tract in

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addition to those of the bone marrow syndrome. Initially, loss of appetite, apathy, nausea, and vomiting occur for 2 –8 h. These effects may subside rapidly. Several days later, malaise, anorexia, nausea, vomiting, high fever, persistent diarrhea, abdominal distention, and infections appear. During the second week of irradiation, severe dehydration, hemoconcentration, and circulatory collapse may be seen, eventually leading to death.

Central Nervous System Syndrome: The central nervous system is generally resistant to radiation effects. A dose higher than 10 Gy is required to cause substantial effects on the brain and the nervous system. Symptoms include intractable nausea and vomiting, confusion, convulsions, coma, and absent lymphocytes. The prognosis is poor, with death in a few days.

Acute Regional Effects: When enough radiation is delivered locally to a certain part of the body, as in the case of radiation therapy, which focuses on a certain field, acute effects can appear in the exposed area. Examples include skin erythema and gastrointestinal edema and ulceration.

Delayed Radiation Effects: There is considerable debate over the effects of low level radiation. On the one hand, there are several theories and reports describing the harmful effects of low level radiation and how underestimated the risks are. At the other extreme, there are theories and reports of harmless and even potentially useful effects of exposure to such levels of radiation. The theories describing the effects of low level radiation and the projected risk estimates of cancer development or genetic effects in humans are purely mathematical and not actual observations. The data from populations exposed to high level radiation were extrapolated to determine the likelihood of these events at low level radiation exposure. Such events in any given population occur at extremely low rates and to further complicate the issue after long latency periods; therefore solid epidemiological data are difficult to obtain.[9]

Cancer is the most important concern of radiation: It has been recognized for more than 90 years that ionizing radiation causes cancers. Tissues with a high rate of cell proliferation are more prone to radiation tumor induction. Cancer becomes evident only long after the first damage is done, following a period of latency. Leukemia first appears at least 2 –5 years after exposure while solid tumors appear after at least 10 years, often several decades later. The tumors reported to be associated with radiation include leukemia, multiple myeloma, and cancers of the breast, colon, thyroid, ovary, lung, urinary bladder, stomach, CNS (other than brain), and esophagus.

Genetic effects: may include changes in the number and structure of chromosomes and gene mutations, dominant or recessive

Cataract: Chronic and acute exposure of the eyes can lead to cataracts secondary to inducing lens fiber disorganization. Not all radiation is equally effective in producing cataracts; neutrons are much more efficient than other types of radiation. In man the cataractogenic threshold is estimated at 2 –5 Gy as a single dose or 10 Gy as a fractionated dose. The period between exposure and the appearance of the lens opacities averages 2 –3 years, ranging from 10 months to more than 30 years [10].

Hypothyroidism: The thyroid gland is exposed to irradiation during radiation therapy of malignant head and neck tumors or the treatment of hyperthyroidism with iodine-131. Patients who received doses of 10 –40 Gy to the thyroid for the treatment of other malignant diseases developed hypothyroidism a few months to many years after exposure. A lower moderate dose of 10 –20 Gy can result in hypothyroidism, while 500 Gy or more is required to destroy the thyroid completely.

Aplastic Anemia: Human exposure to radiation can cause aplastic anemia, depending upon the dose and fractionation. Death may be the end result of aplastic anemia. It has been suggested that permanent anemia is caused by a reduced capability of cellular proliferation due to accumulation of residual injury in stem cells. It is important to realize that when part of the body is irradiated, bone marrow that survives unimpaired will replace what is damaged. If only 10% of active bone marrow escapes irradiation, mortality can be decreased from 50% to zero, based on animal studies.[10]

CONCLUSION

Several biological effects can result from ionizing radiation. These can be due to direct or indirect mechanisms, and they can be acute or delayed. Acute effects occur with exposure to high-level radiation. Delayed effects may appear after a long time and include cancer, genetic effects, effects on the unborn child, and other effects such as cataracts and hypothyroidism. Based on our current knowledge, no level of exposure to radiation can be described as absolutely safe and no level is uniformly dangerous. Radiation doses have to reach a certain level to produce acute injury but not to cause cancer or genetic damage. No biological effects in individuals have ever been documented as being due to levels of ionizing radiation employed for medical diagnosis. Absorbed doses from nuclear medicine procedures are very low. Fear of radiation must not be permitted to undermine the great value of radiation in clinical practice. However, safe handling of all levels of radiation is important to prevent or minimize possible biological effects.

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