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Low dose or low dose rate ionizing radiation-induced health effect in the human

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ABSTRACT

The extensive literature review on human epidemiological studies suggests that low dose ionizing radiation (LDIR) (≤100 mSv) or low dose rate ionizing radiation (LDRIR) (< 6mSv/H) exposure could induce either negative or positive health effects. These changes may depend on genetic background, age (prenatal day for embryo), sex, nature of radiation exposure, i.e., acute or chronic irradiation, radiation sources (such as atomic bomb attack, fallout from nuclear weapon test, nuclear power plant accidents, ^{60}Co-contaminated building, space radiation, high background radiation, medical examinations or procedures) and radionuclide components and human epidemiological experimental designs. Epidemiological and clinical studies show that LDIR or LDRIR exposure may induce cancer, congenital abnormalities, cardiovascular and cerebrovascular diseases, cognitive and other neuropsychiatric disorders, cataracts and other eye and somatic pathology (endocrine, broncho-pulmonary, digestive, etc). LDIR or LDRIR exposure may also reduce mutation and cancer mortality rates. So far, the mechanisms of LDIR- or LDRIR -induced health effect are poorly understood. Further extensive studies are still needed to clarify under what circumstances, LDIR or LDRIR exposure may induce positive or negative effects, which may facilitate development of new therapeutic approaches to prevent or treat the radiation-induced human diseases or enhance radiation-induced positive health effect.

1. Introduction

Low dose radiation is ubiquitous in our environment. With increased abusive use of X-ray computed tomography (CT scan) for medical diagnosis and radiotherapy, the hospital stockpile of nuclear waste is increased tremendously and is now the largest man-made source of radiation exposure to the general population, which contributes about 14% of the total annual exposure worldwide from all sources. Medical radiation from X-rays and nuclear medicine accounts for a mean effective dose of 3.0 mSv per capita per year in Western countries, similar to the radiological exposure of 150 chest X-rays. Approximately 30 million workers are professionally exposed to radiation, and of these, the interventional fluoroscopists (cardiologists and radiologists) are among the most exposed. In fact, their annual exposure is equivalent to 5 mSv per year that would lead to a projected lifetime cancer risk of 1 in 100 after 20–30 years of work (Marazziti et al., 2012). Among patients who underwent cardiac imaging procedures in the Unisted State, the mean cumulative effective dose over 3 years was 23.1 mSv (range 1.5–543.7 mSv) (Chen et al., 2010). A recent study of almost 1,000,000 non-elderly adults in healthcare markets across the United States showed that a considerable number of patients received up to 0.05 Sv/year, a considerable value, given the reference levels for emergency provided by the International Commission on Radiation Protection (ICRP) is among −0.02-0.05 Sv/year (Fazel et al., 2009; Squillaro et al., 2018).

Previous study indicated that ~0·5% of cancer deaths were attributable to diagnostic X-rays in the USA about 30 years ago (Doll and Peto, 1981). Increased construction of more nuclear power plants worldwide and subsequently potential nuclear accidents, occupational radiation exposure, frequent-flyer risks, manned space exploration and possible radiological terrorism have made LDIR/LDRIR research much more imperative and urgent nowadays than ever before, which may explain why many new low dose radiation research institutes have been established recently in different countries worldwide. While high dose radiation-induced human diseases are well known, the effect of LDIR or LDRIR on human health is still underway for extensive scientific research. Available data indicate that LDIR or LDRIR may induce cancer (Hatch &Susser, 1990; Cardis et al., 2005; Busby et al., 2009; Shah et al., 2012), cataract (Ainsbury et al., 2009), cardiovascular diseases (Sumner, 1990, 2007) and long-term psychological consequences

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(Pastel, 2002). However, there exist many uncertainties in esatimating health risks associated with exposure to LDIR or LDRIR in previous studies. These uncertainties significantly affect almost every facet of our lives especially medical care, energy production, homeland security, defense, occupational health and safety, manufacturing and industry, leading to increased unnecessary spending and preventing society from the benefits of using ionizing radiation in state large projects such as building of nuclear power plant and therefore further extensive studies are still needed.

In this paper, we reviewed current progresses on LDIR or LDRIR -induced negative health effect (harmful effect to organism especially different human diseases) and positive (beneficial effect to organism) in the human. These data may provide some clues for better understanding LDIR or LDRIR -induced human diseases, and for search therapeutic approaches using LDIR or LDRIR to improve human diseases. According to different international nuclear agents, the "low dose" is defined as those of 100 mSv or less (≤100 mGy), and the "low dose rate" is defined as those of 6 mSv or less per hour (< 6mSv/h) (UNSCEAR, 2000; Task Group, 2004; National Council on Radiation Protection (NCRP) and Measurements, 2001; ICRP, 2007).

2. Low dose radiation-induced human diseases

2.1. Cancer

2.1.1. Different radiation sources and carcinogenesis

2.1.1.1. Radiation exposure from nuclear war, fallout from nuclear weapon test and nuclear power plant accidents and nuclear contamination (Table 1). Low dose and dose rate radiation-induced human cancers have been well documented (Pierce and Preston, 2000; Brenner et al., 2003; Krestinina et al., 2005, 2007; 2013; Hwang et al., 2006, 2008; Watanabe et al., 2008; Shore et al., 2010; Duport et al., 2012). In a case–control study of leukemia in Utah in relation to fallout from the Nevada nuclear test site, a significant excess risk for acute leukemia was reported in individuals who died at younger than 20 years of age and had received bone-marrow doses from 6 to 30 mSv (Stevens et al., 1990). An increase in leukemia risk was also suggested in children under age 5 years who were exposed to fallout from nuclear weapons testing (estimated fallout marrow dose, 1.5 mSv) (Darby et al., 1992) and children residing in vicinity of 14 nuclear power plants in Germany (Hoffmann et al., 2007) and U.S. (Hatch and Susser, 1990; Mangano et al., 2003). Among atomic bomb survivors, there was a statistically significant cancer risk at the radiation doses less than 100 mSv (Pierce and Preston, 2000; Brenner et al., 2003). In the Techa River cohort who received chronic low dose and low-dose rate exposures from environmental radiation releases associated with the Soviet nuclear weapons programme, significant increases in solid cancer risks were observed, which appeared to be linear in dose (Krestinina et al., 2005, 2007, 2013). Taiwanese exposed to prolonged low dose rates of radiation as a result of occupying buildings containing ^{60}Co-contaminated steel had increased risks of developing different cancers such as breast cancers and leukemia excluding chronic lymphocytic leukemia in specific subgroups of this population (Hwang et al., 2006, 2008). Childhood cancer (under five years, mainly leukaemia) in the vicinity of 16 nuclear power plants in Germany also increased (Kaatsch et al., 2008; Spix et al., 2008). A high risk for cancers was also reported in Hiroshima survivors exposed to very low doses of A-bomb primary radiation at even < 5 mSv (Watanabe et al., 2008). Mortality from stomach, lung, liver, colon, breast, gallbladder, esophagus, bladder and ovary cancer increased significantly for the survivors (Ozasa et al., 2012). In a combined infant population of 15,466,845 born in the UK (internal radiation exposure: 0.02 mSv), Germany (0.06 mSv) and Greece (0.2 mSv) between 1980 and 1990, a statistically significant excess risk for leukemia in those born during the exposure period of 01/07/86 to 31/12/87 after Chornobyl nuclear plant accident was observed when compared with those born between 01/01/80 and 31/

Table 1
Chronic low dose/dose rate radiation induced cancers in the human: radiation exposure from nuclear war, fallout from nuclear weapon test, nuclear power plant accidents and nuclear contamination.

Human population group	Radiation source	Exposure period and dose	Endpoint biomarkers	Endpoint biomarker changes and types of cells monitored	References
Residents living within a 10-mile of nuclear plant	US nuclear plant (Three Mile Island)	Cancer case from 1975 to 1985, radiation dose rate: 0.057–0.105μSv/h	Childhood leukaemia	Significant increase in leukemia case	Hatch and Susser, 1990
Population exposed to fallout from nuclear tests	Fallout from nuclear tests fallout in southwestern Utah	From 1952 to 1958, with bone-marrow doses from 6 to 30 mSv	Leukemia	Increased risk for acute leukemia	Stevens et al., 1990
Children aged under 15 years form Nordic countries	Fallout from atmospheric nuclear weapons testing	During the 1950s and 1960s with red bone-marrow dose < 1.5 mSv	Childhood leukaemia	Increased risk for leukemia	Darby et al., 1992
Survivors of A-bomb attack	A-bomb	After A-bomb attack with γ- ray equivalent dose < 100 m Sv	Solid cancer incidence from 1958 to 1994, 1950–1997, or 1950–2003	A significantly increased incidence of solid cancer	Pierce and Preston, 2000; Brenner et al., 2003; Watanabe et al., 2008; Ozasa et al., 2012
Children living near nuclear facilities 30 mi (48 km)	Nuclear power plant	Cancer incidence for children < 10 yr of age	Cancer incidence	Elevated childhood cancer incidence	Mangano et al., 2003
Children (< 15y) living within a 5-km radius	Krümmel nuclear power plant.	During 1990–2005	Childhood leukemia	Significant increase in leukemia case	Hoffmann et al., 2007
Techa River Cohort exposed to nuclear waste from Mayak Radiochemical Plant	External γ-rays, internal ^{90}Sr, ^{137}Cs etc	Live there from 1950 to 1960	Cancer incident rate and mortality	Low-dose, low-dose rate exposures lead to significant increases in solid cancer risks and mortality. The risks associated with low-dose rate exposures are not necessary less than those seen following acute exposures.	Krestinina et al., 2005, 2007, 2013
Taiwanese residents lived in ^{60}Co-contaminated building	γ- rays	About 10 years at 48 mSv	Cancer risk	Protracted low-dose radiation increased cancer risks, especially for breast cancers and leukemia	Hwang et al., 2006, 2008
European infant (0-1y) pre-natally exposed to fallout of Chernobyl accident	γ- rays, ^{131}I, etc	Pre-natal exposure at < 2 mSv	Leukemia	Increased infant leukemia numbers	Busby et al., 2009