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EFFECTS OF RADIATION EXPOSURE ON THE HUMAN MICROBIOTA: UNDERLYING BIOLOGICAL MECHANISMS AND HEALTH CONSEQUENCES

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Abstract. Radiation is a physical factor that, under certain conditions, can cause significant biological damage at the cellular and molecular levels. While low-level background radiation is a constant part of our environment and generally poses minimal risk, exposure to elevated levels—whether occupational, accidental, or therapeutic—can disrupt physiological systems and impair host–microbiome interactions. Recent studies have highlighted that radiation not only affects human cells directly, but also influences the composition, diversity, and functionality of the human microbiome, particularly in the gut. The microbiome plays an essential role in regulating immune responses, metabolic pathways, and maintaining epithelial barrier integrity. Ionizing radiation, through the generation of reactive oxygen species, DNA damage, and altered immune signaling, can lead to microbiota dysbiosis, reduced microbial diversity, and increased susceptibility to infection and inflammation. Moreover, changes in microbial populations under radiation stress may affect host resilience, recovery, and long-term health outcomes, including increased risk for malignancies and immune dysfunction. This paper explores the mechanisms by which ionizing and non-ionizing radiation affect microbial ecosystems within the human body and underscores the importance of preserving microbial balance in radiobiological research and medical applications. Understanding these interactions opens the door for microbiome-targeted interventions and bioprotective strategies in radioprotection.

Keywords: Ionizing radiation, human microbiome, oxidative stress, immune system, dysbiosis, radiobiology, microbial ecology.

The nucleus of an atom contains protons and neutrons. There is a concept of an unstable atomic nucleus, which, under a certain set of circumstances, has excess energy that tends to break out. If this happens, the following processes can be observed:

- the emission of small particles containing two neutrons and two protons from the atomic nucleus. This phenomenon is called alpha decay;
- the transformation of a proton into a neutron in the nucleus and, conversely, a neutron into a proton - with the release of beta particles. These are electrons or electron twins, which are called antielectrons;
- excess energy is released from the atomic nucleus. It is an electromagnetic wave. This phenomenon is called gamma decay.

Regardless of the type of radiation, we are talking about a high-energy stream of particles. The speed of their movement is enormous: from tens and hundreds of thousands of kilometers every second.

Under natural conditions, cells are constantly being born and dying inside us. If we are talking about radioactive radiation that does not exceed natural limits, radiation particles can damage up to 8,000 DNA bonds every hour, after which they are repaired independently. It is no coincidence that there is an opinion among doctors that radiation received by a person in small doses helps to activate the immune system. However, large doses of radioactive substances act exactly the opposite, completely destroying both the immune system and the entire body as a whole.

High doses of radioactive radiation have a detrimental effect, first of all, on the hematopoietic system. Radiation almost completely destroys lymphocytes responsible for immune defense, and the number of irreversible genetic defects at the chromosomal level increases in the cells.

The average maximum permissible radiation dose for humans is about 1 ml sieverts annually. If we are talking about irradiation of 17 ml of sieverts, there is an almost one hundred percent probability of a malignant process occurring. As a result of the destructive effects of radiation, DNA structures are deformed, and the destruction process itself can be launched by just one radiation particle, which has the appropriate potential for this.

At the atomic level the picture looks something like this. Highly radioactive particles move at enormous speeds. At the same time, they literally knock electrons out of atoms. As a result, the atoms acquire a positive charge. The electron, now free, enters into a complex reaction with the ionized atom. During this reaction, free radicals are formed. An example is the reaction that occurs between radioactive particles and water.

As you know, water makes up more than 80% of the total mass of our body. When water is exposed to radiation, the water begins to disintegrate into two radicals - OH and H. They are called pathologically active particles. In turn, they come into contact with all molecules present in the body, invading their structure and causing irreversible changes. The number of cells and molecules that are damaged increases, which has a detrimental effect on all metabolic processes. After some time, the affected cells die or their functions are seriously impaired.

What happens to an irradiated body is that because the DNA structure is damaged, it prevents normal cell division, which is the most fatal consequence of irradiation. With large doses of radiation, cells are damaged to such an extent that literally all organs and systems of a person fail. In this case, the heaviest blows fall on organs with the most intense cell division. It's about:

about the lungs;

about bone marrow;

about the mucous membrane of the stomach and intestines;

about the genitals.

It is important to know that any object with a weak degree of radioactivity, if in contact for a long time, can cause irreparable harm to a person. For example, cameras or pendants often act as “time bombs.”

Radiation is dangerous because, affecting a living organism, it initially does not have any external manifestations. It quietly affects most organs, and people do not feel anything.

The degree and nature of exposure may vary and may result in:

to acute radiation sickness;

to damage to the central nervous system;

to local radiation burns;

to cancer;

to malignant blood diseases;

to immune pathologies;

to infertility;

to mutations.

A person does not have a sense organ that could warn him about radiation danger. The only possible protection in such cases is a household dosimeter.

Effect of ionizing radiation

Ionizing radiation refers to a type of energy released by atoms. This energy comes in the form of electromagnetic waves of two types:

gamma radiation;

X-ray radiation;

particles (in the form of alpha, beta particles and neutrons).

Actually, radioactivity is nothing more than the result of the spontaneous decay of atoms. When atoms decay, they always produce excess energy or a form of ionizing radiation. The instability of the atomic nucleus has already been mentioned. Those elements that are unstable, arise during nuclear decay and emit ionizing radiation are called radionuclides. In turn, radionuclides are usually identified based on the type of radiation they emit, its energy and half-life.

Every day we are exposed to both natural and artificial radiation. Natural sources should be understood as more than 60 substances, the habitat for which is soil, air and water. For example, the formation of radon gas occurs naturally in rocks. Every day we receive a certain amount of radionuclides that are found in food, water and air.

If a person is at too high an altitude, cosmic rays begin to affect him. Overall, about 80% of the radiation dose we receive each year is background radiation in the form of terrestrial and space sources. The levels of radiation in them are different. Sometimes they can be 100 or 200 times the average.

In addition to natural sources of ionizing radiation, we can also be affected by sources of artificial origin. First of all, this is the production of nuclear energy at nuclear power plants. Medical equipment used for diagnostic and therapeutic purposes is also an artificial radiation source.

The degree of damage to a living organism by radiation exposure is determined by the received radiation dose or absorbed dose. It is expressed in units called grays (Gy). As for the effective dose used to measure radiation indicators and the level of its harm, it is measured in sieverts (Sv). In this case, the type of radiation exposure and the degree of sensitivity of a particular organ or tissue are taken into account. Measuring the level of radiation in sieverts helps determine how severe the damage it will cause.

milli- and microsieverts are often used for measurement purposes . In addition to the main indicator of radiation (its dose), sieverts are also used to indicate the rate at which this dose is released into the environment (for example, microsieverts per hour or year).

There are:

internal exposure to radiation;

external influence of radiation.

Internal exposure occurs when radionuclides are inhaled or absorbed through any route. For example, they can enter the body through a wound or injection. The cessation of internal exposure to radionuclides occurs when they are spontaneously eliminated from the body or during treatment.

External radiation exposure occurs when radiation from the air enters the skin or clothing. Radionuclides can enter through dust particles, aerosols or any liquid.

In addition, the impact may be:

planned, for example, as a result of the use of medical equipment for therapeutic or diagnostic purposes. Planned exposure also includes the use of radiation in the fields of industry and science;

as a result of the action of already existing sources. This is radon found in residential buildings, or background radiation. In such cases, appropriate control measures must be taken.

And finally, the last type of impact is in an emergency situation resulting from an unforeseen event. Such situations require immediate and emergency measures, since we are talking about a nuclear emergency or a deliberate action by attackers.

The Sun is a star, and its interior is a place where strong thermonuclear reactions constantly occur. They are accompanied by powerful bursts of energy. Solar radiation is usually divided:

to infrared radiation;

to ultraviolet radiation.

Solar radiation refers to electromagnetic radiation with a flux of particles. This involves both the visible and invisible spectrum of radiation. The propagation of solar radiation occurs by electromagnetic waves at a speed equal to the speed of light. Thus, it enters the Earth's atmosphere:

straight;

absent-minded.

The level of damaging effect of penetrating radiation is also determined by the dose, which depends on the nuclear weapons. The power of the explosion and its type are also of great importance, as is the distance from its center. An interesting fact is that when it comes to explosions with low and medium power, penetrating radiation will affect objects much less than the shock wave and light radiation. Penetrating radiation is considered as the main factor of damage when ammunition with low and ultra-low power or neutron-based ammunition explodes. Their radiation arises as a result of processes occurring with fast neutrons.

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