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IONIZING RADIATION IN RADIOTHERAPY

1 Elmurotova Dilnoza Bahtiyorovna,
2 Nurmetova Gulzora Ergashbek qizi,
3 Majlimov Farrux Baxtiyor o'g'li,
4 Qurbonov Jamshid Muyiddinovich
Tashkent Medical Akademy

4 Bozorov Erkin Hozhievich
Institute of Nuclear Physics of the Academy of Sciences of Uzbekistan

Abstract
All types of ionizing radiation that used in radiation therapy are considered. The distributions of X-rays, gamma radiation, and bremsstrahlung X-rays up to 6 MeV and the electron beam in the body are given.

Keywords: radiation therapy, gamma, proton, electron, x-ray, alpha, beta, particle, beam, density, ionization.

Introduction

The main exposure factor available to the radiation therapist is ionizing radiation. Ionizing radiation is radiation that, when interacting with the environment, including the tissues of a living organism, transforms neutral atoms into ions - particles carrying positive or negative electrical charges.

All types of ionizing radiation can be grouped into quantum (photon) and corpuscular.

Quantum radiation includes X-rays, bremsstrahlung X-rays and gamma radiation. Compared to other types of wave radiation (infrared, visible light, ultraviolet), ionizing radiation has a higher frequency, shorter wavelength and much more powerful quantum energy.

Corpuscular radiation includes radiation, which is a stream of elementary particles (electrons, protons, neutrons, negative pi mesons, etc.), as well as decay products of natural and artificial radionuclides (alpha and beta particles).

The source of X-ray radiation is an X-ray tube; This device allows you to receive beams of varying powers, from 100 to 300-350 keV, but this energy is enough to create a maximum dose on the surface of the human body and at shallow depths, so this type of radiation is used to influence various superficial tumors and subcutaneous formations. In the depths of the tissues, the dose continuously and rather steeply falls, amounting to only 20% of the exposure dose on the surface of the irradiated object at a generation voltage of 200 kV at a depth of 10 cm.

Gamma radiation is produced as a result of the decay of radionuclides, for example, ^{60}Co. It has a very high energy, 1.25 MeV. It differs from X-ray by shifting the maximum ionization from the surface of the irradiated body by 0.3-0.5 cm in depth, which somewhat reduces the irradiation of the skin. At the same time, the relative depth doses with gamma radiation are higher than with x-rays, and their absorption in soft and bone tissues differs little. All this makes it possible to deliver a large dose of radiation to a tumor located at a depth, with less risk of damage to the skin and surrounding healthy tissue.

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High-energy bremsstrahlung X-ray radiation produced in special installations - linear electron accelerators - gives a completely different dose distribution. In particular, at a photon energy of 25–17 MeV, the maximum ionization occurs at a depth of 4–6 cm. In this case, tissues located in front of this maximum receive no more than half the dose, and there is practically no danger of radiation damage to the skin and surface tissues. Therefore, it is preferable to X-ray and gamma radiation in the treatment of deep-seated tumors. But its disadvantage is the relatively slow decay of the dose beyond the ionization maximum, and therefore the tissues located behind the tumor are also irradiated at a fairly high dose.

But beam of electrons with an energy of 25 MeV creates ionization with its maximum at a depth of 1-3 cm, after which the dose quickly drops (at a depth of 10 cm to almost zero). At a lower electron energy (5-6 MeV), the dose maximum shifts closer to the surface of the body, and at a depth of 3 cm the effect of radiation is already negligible. Bone tissue causes a noticeable decrease in the electron range and the depth of the ionization maximum. It is advantageous to use an electron beam to irradiate shallow pathological lesions. However, two circumstances must be taken into account: a) the tissues located in front of the lesion receive only a slightly smaller dose; b) due to their low mass, electrons tend to scatter, so that the edges of the beam are not clearly demarcated.

Protons and heavy ions (for example, alpha particles) differ significantly from the listed radiation in their physical properties. They spread in tissues almost linearly until the end of the run. At the beginning of the journey, the dose is almost constant, but at the end it increases sharply. This maximum dose at the end of the path (Bragg peak) allows a high dose to be delivered to the irradiated lesion without significant irradiation of the surrounding normal tissue. The range of protons with energies of 120 and 140 MeV is 11 and 14 cm, respectively.

Neutron beams with an energy of 10-15 MeV give a dose distribution similar to that of X-ray radiation: the dose maximum is located directly on the surface of the body.

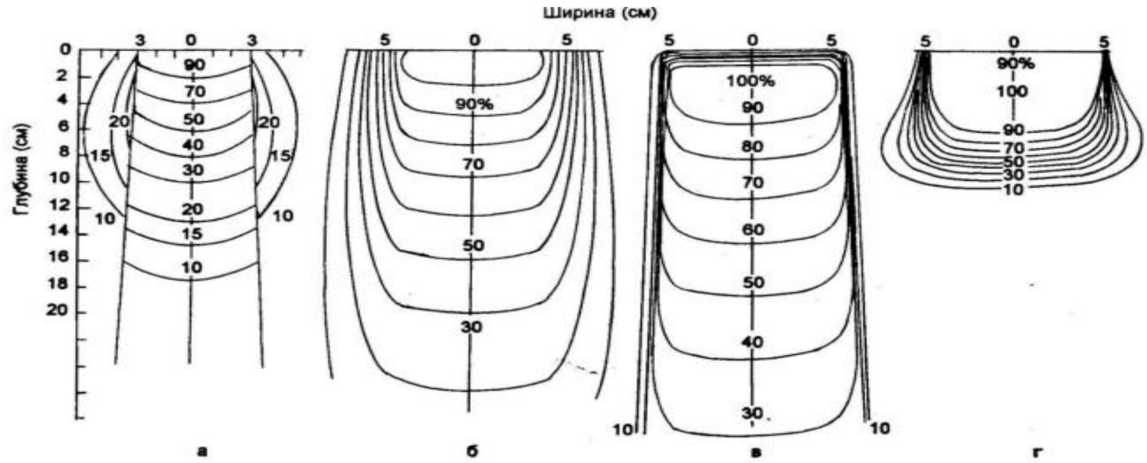

Fig. Typical isodose distributions for different types of radiation: a) X-ray, b) gamma radiation, c) bremsstrahlung X-ray radiation 6 MeV, d) electron beam.

The effect of ionizing radiation on the body begins with a physical process - the interaction of radiation with matter, i.e. with atoms and molecules of tissues and organs. During this interaction, the energy of quanta and particles is spent on ionization and excitation of atoms

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and molecules. Depending on the type of radiation and the amount of energy, the interaction mechanism is different.

But as a result of the interaction of any type of radiation with the medium, the formation of ions of different signs occurs. The work spent by any type of radiation on the formation of one pair of ions in the air depends little on the radiation energy and is approximately 34 eV.

Since the initial energy of a photon or charged particle is much higher (up to 1,000,000 eV or more), they create a huge number of ions on their way through matter. Passing through tissues, different radiations spend their energy differently. Thus, traveling 1 micron through tissue, an electron with an energy of 1 MeV transfers 0.2 keV of energy to the tissue, and an electron with an energy of 30 keV transfers 5 times more; An alpha particle with an energy of 5 MeV gives off even more energy - 100 keV per 1 micron of travel in tissues.

Accordingly, the number of ion pairs formed by these particles (ionization density) will vary (table).

Table Average ionization density per 1 micron.

Type of radiation	Energy of particles or photons	Linear ionization density per 1 micron
X-ray	200 keV	80
X-ray	1 MeV	15
Gamma	1 MeV	11
Electrons fast	25 MeV	8
Neutrons fast	12 MeV	300
Neutrons slow	400 keV	1000
Alpha particles	5 MeV	4500

The formation of ions in a substance that have extremely high activity and the ability to react with neutral atoms and transfer excess energy to them, forming more and more ion pairs, leads to a change in the primary biochemical reactions in those molecules that have absorbed energy. The leading radiation-chemical reaction is the breaking of chemical bonds and the emergence of active free radicals.

In radiation-chemical processes, the primary ionization of water, which makes up about 70% of the mass of the human body, plays an important role. Free radicals H and OH are formed in water, which are highly chemically active. As a result of interaction with them, oxidation or reduction of molecules occurs and the formation of peroxide compounds. Under the influence of radiation, proteins are broken down into amino acids and a number of compounds that are toxic to humans; No less complex reactions occur in lipids, carbohydrates, and nucleoproteins. The structure of molecules changes, tissue respiration is disrupted, the action of enzyme systems, protein synthesis, etc. change. The presence of oxygen in irradiated objects greatly increases the yield of many radiation-chemical reactions.

There are no structures in the cell that are not affected by irradiation - it all depends on the absorbed dose. Cell death during irradiation occurs as a result of the interaction of many types of lesions, primarily nuclear structures (DNA, DNA-membrane complex). Irradiation leads to breaks in the chains of the molecule, the formation of cross-links and other structural

disturbances. If a double-strand break occurs, then such damage is lethal and the cell dies immediately. Other damage is often eliminated due to the cell's ability to restore (repair), which comes in two types: repair of so-called potentially lethal and sublethal damage.
The repair of potentially lethal damage is judged by the survival of irradiated tumor cells when they are dispersed from the tumor not immediately after exposure, but several hours later;
The entire recovery process takes about a day. In this case, cell restoration considered as one of the components of their initial radiosensitivity, which is almost impossible to influence. Most authors consider single-strand DNA breaks as a substrate for cell recovery from sublethal damage. It is generally accepted that repair of sublethal damage is completed 2-6 hours after irradiation, after which the cell is completely restored.
However, the resulting changes in the structure of the DNA molecule (chromosomal aberrations, gene mutations) may be irreversible. For this reason, such cells, which continue to multiply, die after a series of divisions. Giant forms of cells appear in the tumor, their number grows rapidly. An increase in cell size and change in shape contributes to disruption of the permeability of cell membranes. The nuclei enlarge, take on an unusual shape, the cytoplasm vacuolates, mitochondria swell and disintegrate into small grains.
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