T.O. ZHUKOVA
V.F. POCHERNIAYEVA
V.P. BASHTAN

Means of Protecting the Body from the Effects of Ionizing Radiation

STUDY GUIDE

RECOMMENDED
by the Academic Council of Higher State Educational Establishment of Ukraine "Ukrainian Medical Stomatological Academy" as a study guide for students of higher educational establishments of Ministry of Health of Ukraine

Kyiv
AUS Medicine Publishing
2019

UDC 615.849
LBC 53.6ya73
Zh86

Recommended by the Academic Council of Higher State Educational Establishment of Ukraine "Ukrainian Medical Stomatological Academy" as a study guide for students of higher educational establishments of Ministry of Health of Ukraine (minutes No.3, 22 November 2017)

Authors:

T.O. Zhukova — Candidate of Medical Sciences, Associate Professor of the Department of Oncology and Radiology with Radiation Medicine, Higher State Educational Establishment of Ukraine "Ukrainian Medical Stomatological Academy";

V.F. Pocherniayeva — Doctor of Medical Sciences, Professor of the Department of Oncology and Radiology with Radiation Medicine, Higher State Educational Establishment of Ukraine "Ukrainian Medical Stomatological Academy";

V.P. Bashtan — Doctor of Medical Sciences, Professor of the Department of Oncology and Radiology with Radiation Medicine, Higher State Educational Establishment of Ukraine "Ukrainian Medical Stomatological Academy"

Reviewers:

D.S. Mechev — Doctor of Medical Sciences, Professor;

V.S. Ivankova — Doctor of Medical Sciences, Professor, Head of the Research Department of Radiation Oncology, National Cancer Institute, Ukraine;

V.G. Kostenko — Candidate of Philological Sciences, Associate Professor of the Department of Foreign Languages with Latin Language and Medical Terminology, Higher State Educational Establishment of Ukraine "Ukrainian Medical Stomatological Academy";

V.O. Kostenko — Doctor of Medical Sciences, Professor, Head of the Department of Pathophysiology, Higher State Educational Establishment of Ukraine "Ukrainian Medical Stomatological Academy"

Zhukova T.O.

Zh86 Means of Protecting the Body from the Effects of Ionizing Radiation : study guide / T.O. Zhukova, V.F. Pocherniayeva, V.P. Bashtan. — Kyiv : AUS Medicine Publishing, 2019. — 112 p.

ISBN 978-617-505-712-4

The study guide is committed to provide current information about the human body protection against acute and chronic ionizing radiation. The study guide concerns the issues on applying radioprotective chemical agents and natural food items to increase the body resistance against the ionizing radiation in unfavourable environment as well as in the course of radiation therapy. Special attention is paid to the novel conception of radiation protection nutrition. This study guide is designed in accordance with the Curriculum of Radiation Medicine and Radiology to meet the academic, professional needs of medical interns and medical residents of higher medical establishments. It is intended for use by delivering the course of Radiation Medicine and Radiology to medical students.

UDC 615.849
LBC 53.6ya73

ISBN 978-617-505-712-4

Contents

List of Shortenings and Abbreviations

AT — antioxidants
Bq — becquerel
Ci — curie
DNA — deoxyribonucleic acid
DRF — dose reduction factor
FPRP — fundamental principles for radiation protection
FRD — Factor of Reduction of absorbed dose
FR LPO — free radical — lipid peroxidation
Gy — Gray
ICRP — International Commission on Radiological Protection
IRB — ionizing radiation background
LD — lethal dose
LP — lipid peroxidation
PAS — prooxidant-antioxidant system
PUFAs — polyunsaturated fatty acids
ROS — reactive oxygen species

Introduction

Ionizing radiation has since the origin of life been part of the natural environment surrounding all living matter on Earth. Since 1945, when the atomic and later hydrogen bombs were developed, when their intense testing and the extensive development of nuclear energy has started and a range of modern human activities associated has expanded, the amount of energy causing irradiation has been gradually increasing. When released into atmosphere and reaching its upper layers in different ways, radionuclides can distribute fast throughout the globe, falling onto the land surface, oceans and seas.

This has resulted in an increase of environmental background radiation that, it is important to stress, has remained relatively stable over the last few thousand years. Thus, due to growing human activity, all living organisms throughout the planet began to experience additional radiation burden.

That is why the mankind inevitably faces the necessity to design and conduct measures aimed at providing effective radiation protection and safety. In this regard, the researchers worldwide are searching for the best ways to protect from both acute and chronic exposure to ionizing radiation, as well as working out the radioprotective agents to decrease the side effects of radiotherapy.

In Ukraine, the problem of the biological impact of ionizing radiation, particularly in small doses, and protection against is still remaining one of the fundamental issues of medical and biological sciences. Nowadays, the problem is extremely relevant because the Chornobyl nuclear power accident led to huge releases of radioactive materials into the atmosphere deposited over large areas of Ukraine. The consequences of this grievously known accident were associated with the significant environmental radiation pollution of different intensity.

Today we can confidently state that no one doubts the importance of using complex protection, which along with the methods of physical protection, and screening in particular, should involve the appliance of radiation protectors.

All radioprotective agents are divided into two classes — radioprotectants and agents for the treatment of radiation damages.

Radioprotectors are drugs (mostly synthetic) that have the greatest effect when given within some period before the radiation exposure. They are present in the radiosensitive organs (often in the maximum tolerable and subtoxic doses) and prepare the body to develop high radioresistance. The agents for the treatment of radiation damages are usually applied following the irradiation and the development of the main syndromes. They are aimed at overcoming the potential damages by substitution and supportive therapy.

One of the new directions of radioprotective researches is the medium of early pathogenic therapy. This is a special class of compounds that are able to influence on the development of pathologic process under the impact of ionizing radiation on early stages. Analysis of available literature allows us to consider a long-term chronic exposure to ionizing radiation as a lingering radiation stress, backed up by the set of environmental and psychosocial stress agents. Key role in the pathogenesis of the stress is played by the activation of free radical oxidation, increasing antioxidant deficit, immune and neuroendocrine deregulation. Effective means for correction of these changes include antioxidants, anti-stress drugs (adaptogens) and immunomodulators.

Currently, chemical methods of radiation protection embrace the following areas

1. Individual prevention by using radiation protectors that protect the body from external irradiation that causes acute radiation syndrome.
2. Applying means that enhance human body radioresistance during radiation therapy.
3. Applying nutritional supplements and drugs that increase the resistance of biological objects during chronic exposure to ionizing radiation in natural conditions.
4. The removal of radionuclides from the body.

Existing radioprotectors and radioprotection measures are far from being perfect. Literature review points out the fundamental properties of new chemical agents, so-called perfect radioprotectors that must meet the following requirements:

- to provide high efficiency causing no or little toxicity;
- to be manufactured in dosage forms, which are easy to use and are effective delivering the medication as needed;
- to be cost-effective and to have good storage stability;
- to be effective when used at different types of ionizing radiation;
- to provide the protection that must start from the first minutes after the administration and last for a few hours.

Only few radioprotective chemical compounds are widely used in medical practice, but they are ineffective at high lethal doses of radiation. Radioprotectors as means of individual chemical protection may be used in cases of emergency at nuclear power plants to make urgent repairs in conditions of increased radiation exposure or while being in a radiation contaminated environment, for example, during space missions and when taking the course of radiation therapy.

Chapter 1

BIOLOGICAL EFFECTS OF IONIZING RADIATION ON LIVING ORGANISMS

The main biological effect of ionizing radiation consists in its ability to induce functional, anatomical and metabolic changes at the molecular, cellular, organ and organism levels.

Biological effects of ionizing radiation are determined by the energy given to various tissues and organs.

The biological effects of ionizing radiation can be explained by the following processes:

- absorption and deposition of energy by living cells;
- ionization and excitation of atoms and molecules with the following radiolysis and the formation of free radicals, the further development of primary radiation-induced chemical reactions and damage of large molecular compounds.

Primary radiation effects may be direct or indirect. Direct radiation causes excitation and ionization of molecules of tissues and organs.

Ionizing radiation energy transfer occurs in a very short period. The ionization and excitation of atoms and molecules of the irradiated tissue are the primary physical processes that trigger pathological changes.

The characteristics of the biological action of irradiation

1. The biological effect depends on the radiation dose absorbed. This dependence is direct, i.e. an increase in the dose intensifies the effect.

2. The effect of irradiation is also determined by the distribution of a dose in time line, i.e. by the rate of energy absorption. The distribution of the same total dose into separate fractions reduces the degree of radiation damage as the reparative (recovery) process starting immediately after the exposure to radiation, are capable at least to compensate disturbances caused by irradiation.

3. The extent and type of radiation damages depend on the radiation energy distribution throughout the body. The most marked effect is expected when the whole body is exposed to irradiation, so-called the total exposure. Smaller changes are caused by the action of the same dose, when they impact some parts of the body – local irradiation, when the part of the body exposed matters. Most adverse effects are observed in the ab-

dominal irradiation. Less dangerous consequences are caused when limbs are irradiated.

4. The biological effect depends on the type of radiation. According to the value of the linear energy transfer (LET — amount of energy an ionizing particle transfers to the material traversed per unit distance) ionizing radiation is divided into sparsely and densely ionizing radiation.

Sparsely ionizing radiation is irradiation of any physical nature characterized by LET of 10 keV/ μm, i.e. a more homogeneous dose distribution of relatively small energy depositions. Densely ionizing radiation exhibits a heterogeneous dose distribution with high local energy depositions, LET >10 keV/μm. LET of ionizing particles increases with decreasing the speed of the particles, this means that at the end of distance the energy efficiency of any charged particle is maximal. This leads to a specific distribution of ionization that is described by the well-known Bragg curve, when the maximum, Bragg peak, is occurred immediately before the particles come to rest.

Mentioned characteristics of heavy nuclear particles interaction is used in the treatment of tumours, because it enables to focus sufficient energy on the depth of the affected tissue while minimizing its distribution through healthy tissues along the beam course. It has been found out that LET is proportional to the square of the charge: α-particle, which is formed due to the radioactive decay and containing two protons, it has a positive charge of two (+2), determines the appearance of ions 4 times more likely than other particles. In the air, α-particles depending on the primary energy form 40 000—100 000 pairs of ions, while ß-particles produce only 30—300 pairs of ions. The distance of particles increases with their energy.

Unlike charged particles, neutrons do not carry an electrical charge that allows them to penetrate without obstacles into atoms depth. Reaching nuclei, they are absorbed or spread throughout them. During the elastic scattering in carbon nuclei, nitrogen, oxygen, and other elements that make up the tissues, the neutron loses only 10—15% of energy, and when collapses with hydrogen nuclei having almost the same mass — protons — the energy of the neutron decreases on average as much as twice by transferring protons recoil. Due to the elastic scattering of neutrons, highly ionizing protons are formed. Atomic nuclei in the process of the neutron absorption become unstable and, disintegrating, form protons, α-particles and photons of γ-radiation, and are capable of conducting ionization as well.

With such nuclear reactions, radioactive isotopes of elements can be formed and radioactivity arises, which, in turn, also causes ionization. The recoil nuclei, which arise in nuclear transformations, can ionize matter by themselves.

Consequently, in case of neutron radiation, the ultimate biological effect is associated with ionization carried out directly by secondary particles or photons. Thus, the main contribution of one or another type of nuclear interaction of neutrons depends on their energy and composition of the matter emitted.

By the magnitude of energy, four types of neutrons are distinguished: fast neutrons (E >100 keV), intermediate-energy neutrons (E = 100 – 1 keV), slow neutrons (E <1 keV) and thermal ones (E ≈ 0.025 keV).

Fast neutrons are of the most practical value in radiobiology. All others being formed during slowing down also contribute to the overall energy absorption process. Neutrons are accepted as densely ionizing radiation because the recoil protons formed can ionize the matter to a large extent. Protons arise at a large depth at the high penetrating capability of neutrons.

Thus, all types of ionizing radiation by themselves or indirectly result in the impairment or ionization of atoms or molecules of biosystems. However, irradiation of objects with different types of ionizing radiation in the same doses lead to quantitatively, and sometimes qualitatively different biological effects. Therefore, the concept of relative biological efficiency (RBE) of ionizing radiation was introduced. For example, fast neutrons in a dose of 1 Gy (100 rad) produce the same biological effect on humans as 10 Gy (1000 rad) during irradiation.

1. The presence of the latent period. The latent period is the interval elapsed between the radiation insult and the onset of clinically registered effects. The duration of the latent period is inversely proportional to the dose absorbed. The higher dose causes the shorter latent period. It is necessary to remember that the latent period is a conditional clinical concept, and, in fact, the reaction to radiation starts developing immediately.

2. The property of cumulation. If a skin area is exposed to radiation in a dose of 1 Gy, no visible changes occur. If the irradiation is repeated for several consecutive days, erythema appears. In daily exposure to radiation for 2—3 months necrosis usually occurs. This can be explained by the fact that tissues gradually accumulate slight changes caused by each radiation event that ultimately lead to major damages.

Biological effects caused by irradiation are considerably determined by functioning of the integrative systems of the body — the nervous system, the endocrine apparatus and the humoral system that transport the toxic