Significance of beta-radiation skin burns in Chernobyl patients for the theory and practice of radiopathology

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Introduction

Radiopathology is one of the relatively new branches of medical science. Constant development with more precise definitions of separate theses is one of its characteristic features. A lot of lessons were learned from the tragic event – nuclear accident at the Chernobyl nuclear power plant on April 26, 1986. Deeper and more detailed understanding of clinical features, dose dependence and the role of \( \beta \)-radiation skin burns in a general course of acute radiation syndrome (ARS) was one of these lessons. All people were exposed to gamma-beta-radiation.

Widespread radiation lesions on the skin caused by an exposure to \( \beta \)-radiation constituted a distinguishing feature of the injuries sustained by the victims of that accident. Skin lesions were observed in half of the patients with ARS (56 out of 115) and in virtually every patient with the bone marrow syndrome (BMS) to the severe and very severe degree.

As it was reported several times previously \(^1-^3\), most of the accident victims used to arrive to our hospital from 27th to 29th April, so it was necessary to do a triage in order to choose the most appropriate treatment for each patient. Due to the lack of information on the circumstances and especially on the dose of exposure for any individuals at that time, clinical signs of injury were the only help for early diagnosis. Primary skin erythema served as one of the reliable symptoms of radiation injury, and its size on the surface together with the expressed lymphocytopenia was the evidence of the injury severity. Grouping of the patients according to the ARS severity prognosis was performed during the first 3 – 4 days which appeared to be sufficiently correct. Within the nearest few days it became clear that the most severe cases with BMS (resulting from penetrating gamma-exposure) with an early agranulocytosis and deep trombocytopenia were accompanied with extensive and pronounced skin burns. The whole body \( \gamma \)-irradiation doses were established only by the kariologic dicentric blood lymphocite method. All skin injuries were the result of beta-rays exposure.

What had we known about \( \beta \)-radiation effects in man before the Chernobyl accident? The answer was “not too much”. The most detailed description of visible changes on the skin of the people exposed to the bomb testing \(^4,^5\) allowed to consider a \( \beta \)-injury to the skin superficial and not life threatening. Previous experience of our clinic in this field was rather scanty. Radiobiological experimental data \(^6,^7\) gave a lot of information for discussion but did not answer directly to clinical questions.

In general, skin lesions occurred at various times and appeared in the different parts of the body. They were also of

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Značaj opekotina kože izazvanih beta-zračenjem kod černobiljskih bolesnika za teoriju i praksu radiopatologije
different degrees of severity (sometimes even in one particular patient). In most cases they complicated the clinical picture of ARS, while in some patients seemed to be the only cause of death.

- What was the most unexpected for us?
- Diversity of clinical manifestations in skin;
- Unaccustomed course of clinical phases of a radiation injury to skin;
- Significant severity and in many cases the depth of injuries;
- Serious influence of skin burns onto the general state of a patient;
- Necessity of surgical operations in some cases, especially at an early stage.

All these unexpected features of medical consequences of the accident could have been explained if the circumstances of each patient exposure had been known.

In order to better understand the complexity of the accident’s victims’ exposure, a thorough investigation was undertaken. The physicians and physicists used to work together for several months. For a detailed study of the conditions of exposure, the medical history of the patients regarding accidental anamnesis was repeated all the time, and every patient who had survived was interviewed about any circumstances of the accident and the nearest events afterwards. It was necessary to know precisely where and how long the individual and/or his colleagues were at the time of the accident, how they moved from one place to another and so on. They were asked also about their clothing and, when, where and how the decontamination had been performed. The data received from the interview were then compared to the information on radioactive contamination and other information on radiation condition at different points of the site of the accident. That made it possible to reconstruct the most typical situations of exposure and to analyze the examples of exposure with the use of multiplayer skin dosimeters. The importance of the depth of dose distribution for clinical course in case of the local radiation injury was shown previously. This type of dosimeter permits to measure a dose at the depth of 7 mg/cm² and of 150 mg/cm². Thus, it gave a possibility to know a dose to the critical structure of skin: basal cells layer and layer of the dermal blood vessels. The results of these studies were reported previously. It appeared that all patients could be classified into four groups according to (1) the contribution of β and γ components to their total dose, (2) the prevalence of the distant or contact exposure of skin and (3) the nuclide composition of the radioactive sources in question.

The group of the most severely injured patients consisted of the firemen (n=6) who were fighting the fire for 30–40 min on the roof of the Unit 4. They were immersed in the cloud of radioactive smoke and steam, and consequently exposed to a very highly penetrating β- and γ-radiation (distant and contact sources). Their clothing partly protected the skin from β-rays if was dry, but the most part of clothing had got wet and impregnated with radioactive substances. The doses of γ-radiation were estimated to range from 9.0–14.0 Gy. The doses on the skin were more than 200 Gy to the depth of basal cells layer and more than 50 Gy to the depth of dermal blood vessels. Severe lesions of almost the whole skin surface (from 70% to 90% of body surface) were characteristic for the patients in combination with severe bone marrow and intestinal syndrome. Skin injuries developed very rapidly: skin erythema and expressed oedema appeared within the first week, while by the end of the second week an almost total moist desquamation with erosions were observed. All the six patients died by the end of the third week. Skin burns were the main cause of death.

The second group of patients consisted of 15 people. All were exposed to the distant β-γ sources only. The sources of irradiation for this group were the contaminated surface of the floors inside the plant and/or the ground around the plant. They were exposed more than 3–5h within the accident. The energy of β-radiation of nuclides that composed the contamination at that time was in the range of 1.5–3.5 MeV. This together with the γ-component caused a high penetration of irradiation. As has been shown in the experiments to simulate these conditions, the ratios between γ- and β-components were 1:20 at the foot level, and 1:3 at the head level. Since the average range of γ doses for this group was 3.0–4.5 Gy, β-doses on the foot skin could be assessed at 60–90 Gy at the basal cells layer, and 20–30 Gy (three times less) at the level of dermal blood vessels. The doses on the facial skin were 9.0–12.0 Gy, and 3.0–4.0 for two critical depths, respectively.

The majority of the patients in this group showed the injuries to the feet and shins. They were characterized by moist desquamation in the third to the fourth week after the exposure and then after the visible recovery the next, so-called, recurrent wave of erythema with oedema and a numerous ronuous eruptions appeared (50–60 days). On the facial skin, which was less exposed, only erythema was observed after about 15–20 days. All the patients of this group survived ARS, however, within the following two – three years some of them suffered from late radiation ulcers of the foot skin for which some surgical treatment was urgent.

The third group of patients consisted of six persons who were at the time of the accident and for a few hours afterwards at the points at different distances from the plant in the direction to which the radioactive plume was moving. People were exposed to γ-radiation from the smoke constituents in the plume. In addition to this γ-exposure, the skin was exposed to the particles of fallout, which formed the thin radioactive sources on the skin surface. This constituted a contact exposure of the skin.

The most exposed parts of the body were the head (face), neck, shoulders and hands, in this order. The doses of γ- and β-radiation were in proportions from 1:20 to 1:30. The main sources of the skin dose were β-emitters with low energies. Each person in this group was exposed also to distant sources from the contaminated ground. The total body doses due to γ-radiation for this group ranged from 4.0 to 12.7 Gy. The person who had been exposed to the highest dose (12.7 Gy) had very severe and widespread β-radiation burns. At the time of the accident he was 1.0 km far from the plant, and he remained there for an hour. He appeared to be cove-
red with black dust. The decontamination was made rather too late. The experimental reconstruction of this situation and subsequent calculations indicated that the skin of his scalp, face, neck and the upper part of the body were exposed to relatively soft β-radiation, with the doses of about 250–360 Gy to the basal cells level, and of about 30 Gy to the dermal blood vessels. The skin reaction was very quick, very severe, and painful. At the end of the first week there was a widespread erythema with oedema and some blisters, and by the 10th day there was a widespread blistering with erosions and ulceration. The skin burns were within the total area of about 70% of the body surface. The patient died on the 17th day after the exposure.

The two other patients in this group died a little later not of skin injury, however, radiation burns were a complicated factor. The three other patients survived. In the following years, they had some problems with the skin of shins. One person was operated twice for late skin ulceration.

The fourth and largest group consisted of 29 plant operators who were working in the Unit 4 of the plant at the time of the accident and 3-4 hours later. This was the most varied group, since these persons were exposed to the sources of the different types during their presence in and near the plant. A distinguishing feature of the exposure conditions in many cases was the wetting of clothing impregnated with radioactive substances. In some of them only a very localized area was wetted; in other cases there was almost total wetting of the clothes. The wetted areas corresponded to the total or local areas of severe skin lesions. Such wetting of clothes created a thick radioactive source on the surface of the skin and led to very deep skin lesions. The decrease in the dose from the depth of 7 mg cm$^{-2}$ to the depth of 150 mg cm$^{-2}$ was by the factor of 3 and the doses of β-γ-irradiation on the surface of the skin were extremely high (sometimes more than 400 Gy). These skin lesions were followed by death when they covered more than 60% of the total body area. Lesions relatively small in area led to deep necrosis of the skin (dose to the dermal blood vessels more than 30–40 Gy) and surgical interventions, including amputation, were necessary at an early stage in some cases.

There were 30 patients with late effects of skin burns among the Chernobyl accident survivors. A follow-up study of this group conducted by the specialized clinics in Moscow and Kiev showed that the consequences of skin injury were the main cause of their admission to the hospital. Skin atrophy with scars and often ulcers reappearing limited their life activity significantly and a surgical treatment was required. Many of them were reoperated several times (in some cases more than 10 times) using different types of skin plastic surgery. The microsurgery technique was most helpful. During past 19 years no deaths of skin injury were registered.

The best description of the pathological mechanisms of late clinical effects mentioned above can be found in the paper of Peter R. 10, who considered that ionizing radiation affected not only the stem cells but also changed the communicative network of epidermal keratinocytes, dermal fibroblasts, and circulating and resident immunocompetent cells, such as Langerhans cells, dermal dendritic cells and some others.

A dermal and subcutaneous fibrosis developed at the sites of radiation burns in our Chernobyl patient within 6–12 months, or a little later in the cases of relatively lower doses of exposure. Dry, thin skin with a lot of telangiectasias and disorders in pigmentation and tissue immunity appeared to be very easy-wounded and subjected to allergic reaction. Years after the exposure, chronic sequelae, like severe dryness of the skin caused by the loss of sebaceous and sweat glands and increased transepidermal water loss resulted in an increased vulnerability of the skin, often leading to secondary ulceration 10.

It is interesting to note that in the last 3–5 years admitting of patients to the hospital for the late effects (skin ulcers) treatment became more rare. So, a certain stabilization of the pathological process can be regarded.

Conclusions

A clinical study of medical consequences of the Chernobyl nuclear power plant accident in 1986 showed the seriousness of skin lesions resulted from the exposure to β-radiation. They were a component of the general clinical syndrome of acute radiation sickness. The contribution of radiation skin lesions to the aggravation in general state of a patient was determined not only by the extent of the process but also by the degree of the pathological changes and by the duration of the course of the pathological process.

A detailed study of the conditions of the exposure of the patients suffered from skin burns helped to answer the questions related to the feature of beta-burns.

By means of the detailed dosimetric studies for each group of patients and comparisons of the results with the clinical picture, the nature of diversity of skin changes became clear. The dependence of skin lesions on the depth-dose distribution was demonstrated and these data were in good relation with results of an experimental study of skin reaction of pigs to β-irradiation.

In case of the dose on the skin of 50–70 Gy in the basal epithelial cells and not more than 20–25 Gy in the vascular network, recovery of the epithelium, though incomplete, was possible. In other cases with the doses of more than 200–300 Gy in the basal epithelial cells and of more than 30 Gy in the vascular network, no recovery was possible. Deep necrosis of skin developed from the vascular network injury, in case when the dose in skin blood vessels was higher than 50 Gy.

The outcomes and late effects of the lesions depended on the depth-dose distribution and on the size of the area affected. There were not sufficient data for the group exposed to relatively low-energy β-radiation, but it was clear that the exposure of skin to high-energy β-radiation with the doses of more than 200 Gy on the surface could lead to death if the area of the injured surface exceeded 50% of the total body surface. So, the possibility of skin-form of radiation death was confirmed. Pathological changes on the skin after β-irradiation are a complex process.

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