COMPARISON OF THE BIOLOGICAL EFFECT OF STRONTIUM-90, CESIUM-137, IODINE-131 AND EXTERNAL IRRADIATION

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Abstract

In the paper, a comparative estimate of radiotoxic effect of ^{90}Sr, ^{137}Cs, ^{131}I and external irradiation is given. The investigations were carried out on albino rats under the conditions of chronic exposure. In the range of the commensurate doses and exposure times, the relative radiotoxicity of ^{90}Sr, ^{137}Cs and external irradiation according to haematological and biochemical indices and lifespan was found to be close to unity. The effectiveness of ^{131}I according to the same indices was considerably lower. As to the incidences of malignant tumours - the efficiency of ^{90}Sr proved to be in excess of those for ^{137}Cs, ^{131}I and external irradiation.

Introduction

In the recent years, the attention of researchers has been attracted to the problems of comparative assessing a toxic action of nuclides and external irradiation. However, most of these works concerns blastomogenic efficiency of bone-seeking nuclides[1-4].

This report treats the problem of chronic exposure to ^{90}Sr, ^{137}Cs, and external irradiation in its comparative aspect.

Materials and Methods

The experiments were done on albino rats, males and females. A total of 864 test rats was divided into 11 treated groups and a control one. The animals were fed a daily diet containing the nuclides throughout lifespan in the following doses: 2.0, 0.5, 0.05 μCi ^{90}Sr, 25.0, 5.0, 0.5 μCi ^{137}Cs, 0.075 and 0.0075 μCi ^{131}I per kg of body weight per day. The external exposure was delivered at levels of 5.0, 1.0 and 0.2 R/d. These dosages, for all the above types of exposure, were conditionally denoted as "large", "medium" and "small" doses, the absorbed doses at the end of the year being 1500-2300, 240-360 and 40-70 rads, respectively.

The haematological, biochemical, morphological indices, the animal lifespans and the tumour incidences were studied.

Results and Discussion

In the case of ^{90}Sr, ^{137}Cs or external irradiation at "large" doses, the peripheral blood studies have evidenced the short-period initial leukocytos and the prolonged leukopenia advanced gradually. When exposed externally, the leukopenia occured somewhat earlier than in administering ^{90}Sr and ^{137}Cs. No essential differences in the extent of depression in leukopoiesis induced by ^{90}Sr, ^{137}Cs or external radiation have been displayed at the late periods of time (540-660 days). The leukocyte number in these groups was 35-45% lower than in the control one. During the first months, the leukopenia is due to lymphopenia mostly. To the end of exposure, however, the neutrophil number decreased, too.

For the ^{90}Sr, ^{137}Cs and external exposure at "large" doses, the thrombocyte response was generally similar to the leukocyte one, but the reduction in the thrombocyte number took place later and was shown to a lesser degree. For a long time, no quantitative changes in red cells were found. The moderate anaemia has developed in the animals only to the end of the experiment. The reticulocyte number increased markedly at this period.

In the range of "medium" doses, the persistent leukopenia at 7 months postintake occured only in administering ^{90}Sr and ^{137}Cs. To the end of the second year, the leukocyte number in these groups was 20-23% lower than in the control one. When exposed chronically to the same doses of external radiation, the animal response of leukopoiesis depression was unstable. The administration of "large" and "medium" ^{131}I dosages didn't lead to the marked reduction in the formed elements of peripheral blood.

The cytological investigations have given evidence that for all exposures the number of leukocytes with structural disturbances of nucleus and cytoplasm (binucleated lymphocytes, hypersegmented neutrophils etc.) increased in the peripheral blood. When exposed chronically to the "large" and "medium" doses of ^{90}Sr, ^{137}Cs and γ-irradiation, the number of degenerative leukocytes exceeded that in controls to the end of the second year by a factor of 3 and 1.5, respectively. In case of administering similar doses of ^{131}I, the cytological changes in the leukocytes were less intensive.

The presented data give evidence that the modes of changes in peripheral blood at an early and late stages are identical, when exposed to ^{90}Sr, ^{137}Cs and external radiation. To determine the dose-effect relationship, the response of leukopoiesis depression was used as the most specific one for the effect of radiation exposure (Fig.1).

As one can see from Fig.1, the dose-effect relationship can be represented by an exponential function. The course of the curve is apparently influenced by the process of repair.

The analysis of findings shows that the relative toxicity of ^{90}Sr, ^{137}Cs and external irradiation is close to unity. The minimal dose that induces leukopenia is equal to 150-200 rads.

The action of ^{90}Sr, ^{137}Cs and external irradiation of "large" do-

ses has led at early stages to increasing activity of some blood ferments. However, the stimulation phenomena were rapidly replaced by prolonged inhibition of ferment activity. From the 60th day to the end of the observations, the activity of cholinesterase in erythrocytes and serum was 25-35% lower than in control data. In administering ^{131}I, no marked inhibition of ferment activity was observed.

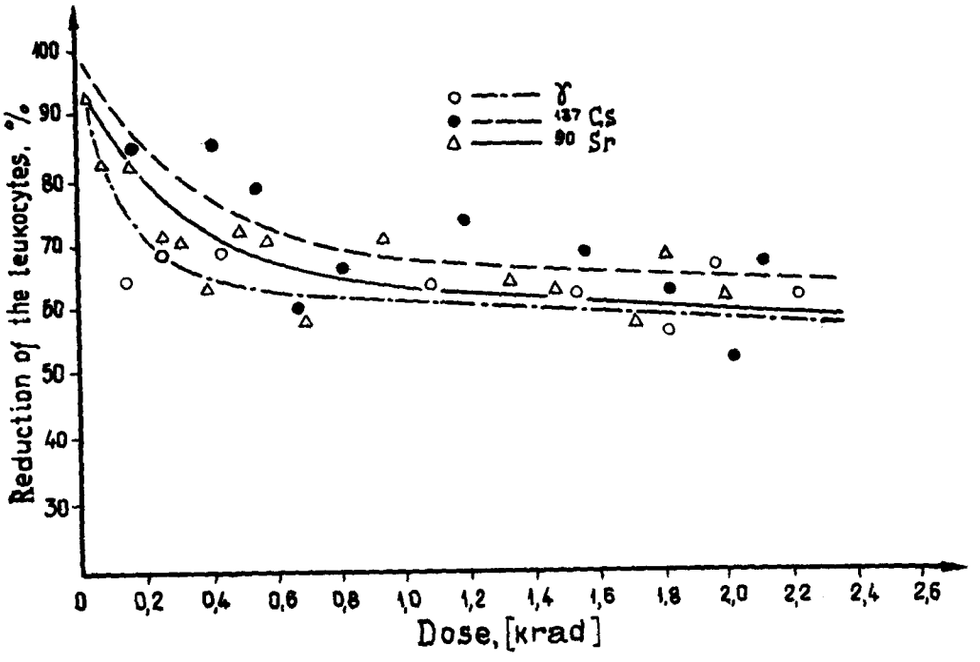

Fig.I. The response of leukopoiesis as a function of the absorbed dose.

When exposed to ^{90}Sr, ^{137}Cs and external irradiation with the same doses, the concentration of residual nitrogen in blood on day 90 exceeded that of control by 45-60% and was kept at this level to the end of the observation. No significant differences in the intensity of reaction, when exposed to ^{90}Sr, ^{137}Cs and external γ-irradiation, have been revealed.

To compare the action of nuclides and external irradiation, times of animal deaths and tumour incidences were studied. The median survival times and its confidence intervals of exposed animals have been determined. The results of calculation are given in Table I.

The significant lifespan shortening was observed among the animals exposed to "large" doses of ^{90}Sr, ^{137}Cs and external irradiation. A slight lifespan shortening has been revealed also for the animals who received 0.5 μCi ^{90}Sr/kg per day. Lifespan shortening was on the average 0.09 day per rad. The mortality curve plotted against absorbed dose was S-shaped (Fig.2).

In exposing to ^{90}Sr, ^{137}Cs and external irradiation, the maximum mortality of animals, when plateaued, was 40, 30 and 34%, respectively, the absorbed dose being 4000 rads for bone tissue and 3000-

Table 1.

The average lifespan of animals for various exposures

Exposure		The number of animals	Median (Me) /days/	95% confidence limits of Me
^{90}Sr	0.40 μCi/d	75	420	372 - 480
	0.10 μCi/d	75	497	430 - 550
	0.01 μCi/d	75	570	530 - 620
^{137}Cs	5.0 μCi/d	74	452	400 - 524
	1.0 μCi/d	74	567	532 - 600
	0.1 μCi/d	74	603	540 - more than 660
^{131}I	0.0150 Ci/d	75	567	500 - 640
	0.0015 Ci/d	75	587	540 - more than 660
γ-irradiation	5.0 R/d	42	446	383 - 501
	1.0 R/d	75	543	480 - 580
	0.2 R/d	75	620	560 - more than 660
control		75	608	540 - more than 660

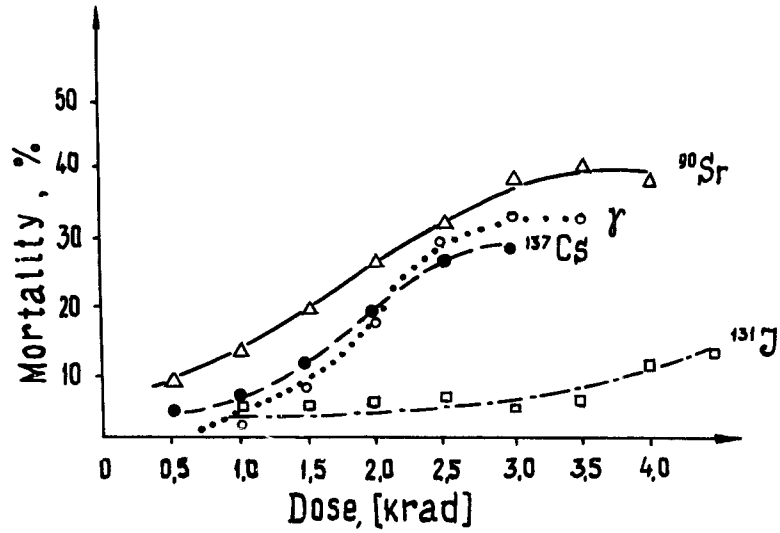

Fig.2. Mortality of animals versus absorbed dose with taking into account the death of control animals.

-3500 rads for whole body. The maximum mortality of animals per 1 rad, when exposed to ^{90}Sr, ^{137}Cs and external irradiation, was the same, being equal to 0.01%. Hence, it follows that the toxicity of ^{90}Sr, ^{137}Cs and external irradiation, when estimated on such criterion as the mortality of animals, is close to unity. Administering ^{131}I has not led to the significant mortality of animals as compared with controls.

The pattern of diseases and the causes of death of the exposed and control animals were identical on the whole. The death of rats was caused mostly by the chronic inflammatory processes in lungs, intestinal and peritoneum. On the background of the above phenomena the individual animals have shown the malignant and benign tumours. The location and incidence of tumours depended upon the types of exposure and the dose (Table 2).

In administering 2 μCi ^{90}Sr/kg per day, the incidence of malig-

Table 2.

The tumour incidence following exposure to "large" doses of radionuclides and external irradiation

Tumours	^{90}Sr	^{137}Cs	^{131}I	γ-irradiation	Control
osteosarcomas	5.0 (6.7%)				
leukosis	3.0 (4.0%)	4.0 (5.4%)	-	2.0 (4.7%)	-
lymphosarcomas	6.0 (8.0%)	-	-	1.0 (2.4%)	-
thyroid adenomas	3.0 (4.0%)	2.0 (2.7%)	5.0 (6.7%)	1.0 (2.4%)	-
thyroid cancer	-	-	2.0 (2.7%)	-	-
parathyroid adenomas	1.0 (1.3%)	1.0 (1.4%)	-	-	-
mammary fibroadenomas	-	4.0 (5.4%)	1.0 (1.3%)	2.0 (4.7%)	1.0 (1.3%)
soft tissue fibromas	-	3.0 (4.0%)	-	1.0 (2.4%)	-
tumours in adrenal glands		-	-	1.0 (1.3%)	1.0 (2.4%)
total of rats with tumours	18.0 (24%)	14.0 (18.9%)	9.0 (12%)	8.0 (19%)	1.0 (1.3%)
total of rats in the group	75 (100%)	74 (100%)	75 (100%)	42 (100%)	75 (100%)

nant tumours was 18.7%. The latent period (the time from onset of exposure to death of animal) was 300-540 days for limphosarcomas and 450-660 days for leukosis and osteosarcomas. The absorbed doses, just before lymphosarcoma appearence, reached 1350 rads, those for leukosis and osteosarcomas did 2200 and 2400 rads, respectively. Limphosarcomas developed from lymph nodes of mesentery or lymphatic tissue of blind gut. Osteosarcomas localized in the femur, usually in its lower third. In addition to the malignant neoplasms, the benign tumours were found in the form of adenomas in thyroid and parathyroid glands.

In administering 25 μCi ^{137}Cs/kg, the incidence of malignant neoplasms was considerably lower and was equal to 5.4%. All the tumours were attributed to the haemopoietic tissue and were developed during the period from 410 to 600 days with the absorbed doses of 1840-2900 rads. At the same time, ^{137}Cs has induced the relatively high percentage of benign tumours.

Administering ^{131}I resulted in the thyroid tumour incidence of 9.4%. The malignant tumours arose with the absorbed doses of 4000-4500 rads.

In the continuous γ-irradiation of animals to the dose of 5 R/d, the incidence of malignant tumours was equal to 7.1% (leukosis, lymphosarcoma). The tumours have appeared for the period of time ranged from 320 to 600 days, when the absorbed doses reached 1600-3000 rads.

In administering ^{90}Sr, ^{137}Cs and ^{131}I at concentration of 0.5, 5.0 and 0.0075 μCi/kg respectively and exposing externally to the dose of I R/d, the total incidence of tumours was 3-6 times lower than in case of the exposure to "large" doses. However, the differences in location and in mode of tumour growth among the individual test groups of animals were kept the same.

The analysis of the total findings gives evidence that according to the haematological and biochemical values and lifespans of animals, the relative toxicity of ^{90}Sr, ^{137}Cs and γ-irradiation is close to unity under the conditions of chronic exposure. The general toxic effect of ^{131}I for the same doses is less pronounced.

Close values of effectiveness of ^{137}Cs and γ-irradiation seem to be determined by the similar spatial and temporal distribution of absorbed doses. In concerning with the ^{90}Sr effect, it should be borne in mind that the latter is not restricted to the critical organ alone. When ^{90}Sr ingested daily, the gastrointestinal tract is exposed considerably together with bone tissue and marrow. In addition, the high energy β-particles escape beyond the bone and expose the hypophysis, the thyroid, as well as the liver, kidney and other organs.

Blastomogenic effectiveness of ^{90}Sr with regard to the induction of malignant neoplasms was found to be higher than those of ^{137}Cs, ^{131}I and external irradiation. Perhaps, it is due to the effect which was compared with the average dose to skeleton without taking the nonuniformity of radionuclide distribution into account. However, this point requires a further experimental investigation.

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