

COMPARATIVE INVESTIGATION OF THE BIOLOGICAL ACTION OF 660 MeV PROTONS, X RAYS, AND γ RAYS

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UDC 612.014.481/.482

Changes in the weight of the spleen and gonads and the ascorbic acid concentration in them and in the bone marrow were studied in rats after irradiation with equal doses of x rays and 660 MeV protons (400 rad) and of γ rays and protons (600 rad). Compared with x rays and γ rays, the relative biological effect (RBE) of the protons on the spleen and bone marrow was less than unity, while on the gonads it was close to unity. The gonads were thus more sensitive to the action of 660 MeV protons than the spleen and bone marrow.

Ionizing radiation causes regular changes in the dynamics of the weight and ascorbic acid (AA) concentration in certain organs [1, 3, 4, 6-9]. The investigation described below was undertaken to compare the action of a single exposure to whole-body irradiation in equal absorbed doses of x rays and protons (400 rad) and of γ rays and protons (600 rad).*

The source of x rays was a type RUM-3 apparatus (180 kV, 15 mA, filter 0.5 mm Cu + 1 mm Al, skin-focus distance 40 cm); the source of γ rays was a type GUBÉ-800 apparatus (dose rate 57 R/min), and the source of protons was a type OIYaI synchrocyclotron. The rats were sacrificed in groups of 10-11 by decapitation at equal times after irradiation. The weight of the spleen and of both gonads, the content of AA in these organs, and the AA concentration in the bone marrow [2] were determined.

The results given in Table 1 show that during the development of radiation sickness as a result of the action of x rays and protons, the dynamics of the indices studied was similar, but x rays caused more severe and lasting disturbances in the hematopoietic tissues. Consequently, with respect to their effect on the hematopoietic tissues, the relative biological effect (RBE) of the protons was less than unity, in agreement with the results obtained by the study of the action of 660 MeV protons and x rays in doses equivalent as regards their lethal effect [5].

No such difference was found in their action on the gonads. Both x rays and protons gave rise to identical patterns of changes in the weight of the gonads and in their AA content. The RBE of the protons relative to the gonads, so far as the indices tested are concerned, was close to unity.

The results given in Table 2 show that γ rays, in an equal dose, caused a more marked decrease in the weight of the spleen and also in the AA content in the spleen and in the bone marrow than resulted from the action of 660 MeV protons. During the action of protons, an earlier onset of regression of these disturbances was observed, suggesting that the RBE of protons for the spleen and bone marrow is lower than that of γ rays.

Equal doses of γ rays and protons caused virtually identical effects in the gonads (Table 2).

*The doses of protons in these experiments were calculated by G. A. Avrunina. According to the calculations of I. B. Keirim-Markus and the results of chemical dosimetry (I. K. Sokolov), the dose of protons was 20-30% lower.

(Presented by Academician V. V. Parin.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 72, No. 10, pp. 47-49, October, 1971. Original article submitted November 6, 1969.

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TABLE 1. Action of X Rays and Protons (400 rad) on Weight (in g) of the Spleen and Gonads, Ascorbic Acid Content in These Organs (in mg), and Its Concentration (in mg%) in the Bone Marrow ($M \pm m$)

Time after irradiation (in days)	Weight of organs				Ascorbic acid content			
	x rays	P	protons	P	x rays	P	protons	P
Spleen								
Control	0,855±0,08	—	0,898±0,07	—	0,416±0,04	—	0,434±0,03	—
1	0,684±0,04	<0,05	0,474±0,02	<0,01	0,227±0,01	<0,01	0,241±0,01	<0,01
3	0,513±0,03	<0,01	0,420±0,02	<0,01	0,170±0,01	<0,01	0,208±0,01	<0,01
7	0,667±0,03	0,01	0,644±0,03	<0,01	0,205±0,01	<0,01	0,234±0,01	<0,01
15	0,871±0,05	0,8	0,826±0,07	0,6	0,289±0,02	<0,01	0,329±0,02	0,01
30	0,915±0,04	0,5	0,923±0,10	0,8	0,364±0,02	<0,2	0,334±0,03	<0,05
60	0,900±0,05	0,7	1,119±0,1	<0,1	0,402±0,01	0,8	0,471±0,02	0,3
90	0,804±0,04	0,5	0,984±0,06	0,3	0,385±0,02	0,8	0,410±0,03	0,6
180	0,658±0,03	<0,01	1,283±0,1	0,02	0,330±0,01	0,02	0,537±0,02	0,02
Gonads								
Control	2,661±0,1	—	2,407±0,09	—	0,764±0,02	—	0,679±0,03	—
1	2,363±0,12	0,1	2,025±0,08	<0,02	0,650±0,04	0,05	0,571±0,04	0,10
3	2,401±0,04	<0,05	2,099±0,09	<0,02	0,612±0,02	<0,01	0,500±0,03	<0,01
7	2,328±0,1	<0,05	2,117±0,07	<0,02	0,541±0,02	<0,01	0,532±0,02	<0,01
15	2,247±0,09	0,01	2,053±0,09	<0,02	0,465±0,01	<0,01	0,476±0,02	<0,01
30	1,548±0,04	<0,01	1,383±0,06	<0,01	0,356±0,02	<0,01	0,372±0,03	<0,01
60	1,118±0,06	<0,01	1,007±0,06	<0,01	0,443±0,03	<0,01	0,371±0,03	<0,01
90	1,916±0,11	<0,01	1,595±0,1	<0,01	0,580±0,03	<0,01	0,434±0,04	<0,01
180	2,128±0,09	<0,01	2,212±0,2	<0,1	0,596±0,03	<0,01	0,565±0,05	<0,01
Bone marrow								
Control	—	—	—	—	24,0±0,77	—	25,5±0,68	—
1	—	—	—	—	—	—	22,3±1,3	0,02
3	—	—	—	—	20,5±1,56	<0,02	16,2±1,2	<0,01
7	—	—	—	—	18,0±1,30	<0,01	31,1±2,6	0,1
15	—	—	—	—	25,1±1,25	0,6	30,8±2,9	0,2
30	—	—	—	—	23,7±1,07	0,8	28,8±2,1	0,2
60	—	—	—	—	23,0±1,25	0,6	26,0±3,1	0,8
180	—	—	—	—	21,1±1,23	<0,05	27,7±2,0	0,1

TABLE 2. Action of γ Rays and Protons (600 rad) on Weight (in g) of Spleen and Gonads, Ascorbic Acid Content (in mg) in These Organs and Its Concentration (in mg%) in the Bone Marrow ($M \pm m$)

Time after irradiation (in days)	Weight of organs				Ascorbic acid content			
	γ rays	P	protons	P	γ rays	P	protons	P
Spleen								
Control	1,260±0,09	—	0,835±0,04	—	0,567±0,03	—	0,389±0,02	—
1	0,648±0,05	<0,01	—	—	0,217±0,02	<0,01	—	—
3	0,397±0,04	<0,01	0,812±0,10	0,8	0,161±0,01	<0,01	0,261±0,02	<0,01
7	0,566±0,06	<0,01	0,820±0,10	0,9	0,232±0,02	<0,01	0,234±0,02	<0,01
15	0,843±0,09	<0,01	1,022±0,09	0,1	0,313±0,06	<0,01	0,353±0,03	0,4
30	1,018±0,08	<0,05	0,908±0,06	0,3	0,394±0,04	<0,01	0,325±0,01	0,05
Gonads								
Control	2,474±0,10	—	2,288±0,05	—	0,697±0,01	—	0,620±0,02	—
1	2,330±0,09	0,50	—	—	0,604±0,02	0,01	—	—
3	2,124±0,09	<0,05	1,874±0,08	0,01	0,596±0,03	<0,01	0,477±0,03	<0,01
7	1,970±0,12	<0,05	1,987±0,10	0,05	0,479±0,04	<0,01	0,461±0,04	<0,01
15	1,823±0,09	<0,01	1,904±0,05	0,01	0,401±0,03	<0,01	0,421±0,02	<0,01
30	0,939±0,01	<0,01	1,157±0,08	<0,01	0,232±0,02	<0,01	0,306±0,02	<0,01
Bone marrow								
Control	—	—	—	—	24,3±1,8	—	24,9±0,60	—
1	—	—	—	—	11,1±0,9	<0,01	—	—
3	—	—	—	—	11,3±1,0	<0,01	24,6±2,5	0,9
7	—	—	—	—	9,6±1,0	<0,01	20,1±1,2	<0,01
15	—	—	—	—	18,3±1,0	<0,01	28,6±1,1	<0,02
30	—	—	—	—	19,7±0,9	<0,05	27,3±1,6	0,2

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