The Effect of Roentgen Rays upon the Electrical Excitability of the Human Eye

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INTRODUCTION

It was reported by Brandes¹⁾ that a sensation of light was evoked by Roentgen rays. Since then this phenomenon has been investigated by Newell and Borley,²⁾ Belluci,³⁾ Lipetz⁴⁾ and others. Lipetz⁴⁾ showed that the Roentgen rays produced a lowering in responsivity of the retina to light and Roentgen rays, taking spike potentials from ganglion cells of the frog retina as an index. Recently Tarusawa *et al.*⁵⁻⁷⁾ found that the electrical excitability of the eyes decreased following an irradiation of the human body by Roentgen rays for the purpose of Roentgen therapy, and interpreted this phenomenon as a secondary effect of the general serological effect induced by Roentgen ray intoxication. More recently Motokawa *et al.*⁸⁾ suggested that such decreases of the electrical excitability of the eyes as observed by Tarusawa *et al.* was a local effect of Roentgen rays on the eyes, instead of a general effect upon the body.

In the present experiment, measurements of the electrical excitability of the eyes after Roentgen irradiation were carried out in order to get more detailed information about the mode of action of Roentgen rays, as revealed by the method of electric flicker.

EXPERIMENTAL

Method

The method of electric flicker was used to measure changes of the electrical excitability of the eyes.

The apparatus used in the present experiment was the same as was described in the previous report. Sinusoidal alternating currents of 20 cps. were applied to the eyes through a pair of silver electrodes of 2×2 cm.² in size, placed on symmetrical parts of the skin of the outer corner of the eyes. The illumination in the whole visual field was 10 lux and was kept

as uniform as possible. The stimulating current was increased automatically from zero at a constant rate of $12 \mu\text{A}$ per second to determine the threshold for appearance of electric flicker, S_1 . The threshold for disappearance of flicker, S_2 , was determined by lowering the current from a sufficiently high level at the same rate as above. The difference of both sorts of threshold, $S_1 - S_2$, was denoted by ΔS . The time course of ΔS was studied after Roentgen irradiation of the eyes. For this purpose four or five values of ΔS were measured in succession and their average was plotted as a point in the ΔS -time curve.

Conditions of Roentgen irradiation were as follows: Secondary electric voltage was 70 K.V. Electric current was 4 mA. Filter used was an aluminium plate 1.0 mm. in thickness. Area of irradiation $10 \times 10 \text{ cm.}^2$ Distance from the focus to the skin was 30 cm. in the experiment of brief irradiation and 180 cm. in the protracted irradiation, in which a dose of 2.0 r was irradiated for a period of 20 minutes. Dose of scattered Roentgen rays on the eyes was measured by a density meter.

Results

Values of electric flicker, ΔS , were measured before and after a brief irradiation of the eyes with Roentgen rays of 0.5, 1.0 and 2.0 r. The data obtained are shown in Table I. The effect of a Roentgen irradiation

TABLE I
Changes of ΔS before and after Roentgen Irradiation

Dose in r	Subjects	Electric flicker values, ΔS , in μA								
		Before	5	10	15	20	30	40	50	60
0.5	J.U.	15.6	15.0	19.2	22.8	25.2	18.0	18.6	12.9	
	S.K.	13.2	18.0	24.2	24.0		22.2			15.6
	M.K.	18.0	21.6	22.5	24.0	20.4	25.8	19.8		
1.0	J.U.	13.5	21.0	21.0	21.0	24.0	19.8	15.8	10.2	
	S.K.	24.0	26.0	39.6	46.2	34.8	27.0	24.0		
	M.K.	18.6	17.4	21.6	22.8	29.4	19.6	23.4	19.2	
2.0	J.U.	13.2	16.2	23.4	21.0	21.0	24.6	14.4	13.3	
	S.K.	27.6	37.8	36.6	51.6	52.8	49.8	51.0	28.2	27.3
	M.K.	19.8	27.0	30.6	39.6	32.6	33.6	30.6	28.8	24.6

appeared with a latency of some minutes, attained a maximum in about 15–20 minutes and disappeared in about 30–60 minutes. In these cases the time to the crest depended little on the intensity of Roentgen rays,

but the recovery time tended to become longer as the intensity increased. The relation between the intensity of Roentgen rays and ΔS is shown in Fig. 1, in which per cent increases of ΔS above the resting level are plotted against the intensity of Roentgen rays. As can be seen in this figure, the increase of ΔS is almost linear to the increase of intensity of Roentgen rays up to 0.5 r, but the rate of increase declines at the higher intensities. As mentioned in the previous report, the threshold intensity of Roentgen rays to produce a noticeable increase of ΔS was from 0.1 to 0.4 r. The present experiment shows that ΔS depends on the intensity only in a narrow range of intensities, and remains almost independent of the intensity at higher intensity levels.

Fig. 1. Effects of intensity of Roentgen rays upon electric flicker values, ΔS . Ordinates: Per cent increases of ΔS above resting level (ΔS_0). ΔS : Difference between threshold for appearance of electric flicker and that for disappearance.

Next, the effect of prolonged exposure upon ΔS was measured, the total Roentgen dose being limited to 2.0 r. The data are shown in Fig. 2, in which arrows A and B indicate the beginning and the end of irradiation. As can be seen in this figure, values of ΔS increased 5 minutes after the onset of irradiation, and attained a maximum in 15–20 minutes to recover to their initial level in 40–60 minutes. Comparing these result with those obtained by brief irradiation of 2.0 r, the latency was much longer in the former case than in the latter, but time courses except the latency were found similar in both cases. Moreover, there was little difference in the increase of ΔS . It seems likely that the effect of Roentgen rays depends on the total dose of Roentgen rays irrespective of stimulus duration.

Fig. 2. Changes of electric flicker values, ΔS , following Roentgen irradiation of 2.0 r. Abscissae: Time in minutes from onset of Roentgen irradiation. Arrow A indicates onset of irradiation and arrow B end of irradiation.

In order to assure that the change of ΔS following irradiation of Roentgen rays was due to the local effect on the eyes, a control experiment was carried out as follows: The eyes were covered with a lead plate 10×10 cm.² in size and 2.5 mm. in thickness, and then ΔS was measured after irradiation as mentioned above. The data obtained are shown in Table II. As can be seen in this table, no remarkable increase of ΔS can be observed after irradiation in doses of 0.5 r, but a noticeable increase of

TABLE II
Changes of ΔS before and after Roentgen Irradiation,
Measured with Both Eyes Covered with Lead Plate

Dose in r	Subject	Electric flicker values, ΔS , in μA				
		Before	Minutes after irradiation			
			5	10	15	20
0.5	J.U.	12.0	12.6	13.2	16.8	12.0
	S.K.	19.2	21.0	21.0	17.4	16.5
	M.K.	23.1	19.8	20.4	22.8	16.8
1.0	J.U.	12.0	18.6	18.0	15.0	16.5
	S.K.	20.4	21.0	26.4	24.3	20.1
	M.K.	15.6	22.2	28.5	21.6	13.8
5.0	J.U.	12.0	17.7	21.0	15.0	12.0
	S.K.	13.5	18.0	18.0	17.4	13.5
	M.K.	11.1	16.8	21.0	22.5	17.1

ΔS can be seen after irradiation in doses of 1.0 and 5.0 r. In an attempt to interpret this finding, the following experiments were performed. As can be seen in Fig. 3 A, both eyes were covered with the same lead plate

Fig. 3. Arrangement for measuring scattered Roentgen rays. (A) C : Cylinder cone of Roentgen ray apparatus. F : Roentgen ray film. L : Lead plate 10×10 cm². in size and 2.5 mm. in thickness. A Roentgen film was placed under the lead plate. (B) L₁ : Lead plate 2.0 mm. in thickness. L₂ : Lead plate 0.5 mm. in thickness. L₃ : Lead plate 2.5 mm. in thickness.

as used in the above experiment and a Roentgen film was inserted between the eyes and the lead plate, and then scattered Roentgen doses were measured by the degree of blackening of the film. Results were as follows: No scattered ray was detected following irradiation with 0.5 r, but appreciable blackening occurred after irradiation of 1.0 r and 5.0 r. Judging from the degree of blackening, the observed dose of scattered rays was equivalent to 0.3 r in the irradiation with 1.0 r and to 0.4–0.45 r in that with 5.0 r. In view of our previous experiment showing that the threshold intensity of Roentgen rays to produce a noticeable increase of ΔS ranged from 0.1 to 0.4 r, it is apparent that the observed increase of ΔS in the latter two cases is due to scattered Roentgen rays. The question now arises as to whether the scattered rays into the eyes originate from the uncovered face region. As is shown in Fig. 3 B, a Roentgen film was placed on a lead plate L₃, 2.5 mm. in thickness, and the film was covered with two lead plates L₁ and L₂. The lead plate, L₁, was 2.0 mm.

in thickness and the other, L_2 , was 0.5 mm. in thickness and had a waved surface so as to make a gap between the film and the lead plate, L_1 . With this arrangement no scattered rays could be detected after irradiations with 0.5, 1.0 and 5.0 r. From this control experiment it may be said that the scattered rays into the eyes originated from the uncovered face region. As reported previously, no increase of ΔS was observed in the cases of irradiation with 0.5, 1.0 and 5.0 r of the legs, the abdomen and the chest regions. In accordance with this observation no scattered rays could be detected under the same experimental conditions as in the previous experiments. Only in the case of irradiation of the chest region, scattered rays into the eyes were detected in doses of 0.15 r following irradiation with 5.0 r. But this is obviously below the threshold for ΔS -increases. There is no doubt about the local effect of Roentgen rays as the cause of ΔS -increases.

Roentgen rays are said to act directly upon the receptor system of the retina and to cause a similar effect to visible light. Therefore, it is an important question whether or not the increase of ΔS after Roentgen irradiation of the eyes is comparable with the effect of visible light. The eyes of the observer were adapted to a constant illumination of 50 lux, and then the eyes were exposed to light of 1,000, 5,000 and 10,000 lux for a period of ten minutes respectively. After removal of the light the time course of ΔS was measured under constant illumination of 50 lux. The data obtained are shown in Fig. 4, in which the ordinates represent increases of ΔS above the resting level, that is, $\Delta S - \Delta S_0$, and the abscissae

Fig. 4. Changes of electric flicker values, ΔS , following illumination of the eyes with white light. Ordinates: Increases of ΔS above resting level. Abscissae: Time in min. from onset of illumination. Arrows indicate onset and end of illumination.

time in minutes. The data for 1,000, 5,000 and 10,000 lux are marked by crosses, triangles and circles respectively. As can be seen in this figure, values of ΔS increased abruptly after the onset of illuminations of 1,000 and 5,000 lux, but showed a tendency to decrease gradually during illumination. Immediately after removal of the light, ΔS decreased further temporarily, and then increased again slightly to return gradually to the initial level. When the intensity was as high as 10,000 lux, ΔS increased continuously up to the end of the illumination, and after removal of the light very quick recovery resulted. In short, the latency and the time course of recovery were much shorter for visible light than for Roentgen rays. Apart from this difference, it must be emphasized that no sensation of light was caused by Roentgen rays of the dose used in the present experiment, while very strong sensations were caused by ordinary light.

DISCUSSION

As described in the previous report, the threshold intensity of Roentgen rays to produce a noticeable increase of ΔS is lower than the threshold intensity for Roentgen phosphene of the eyes. Therefore, the observed effect of Roentgen rays near the threshold can not be accounted for in terms of the after-effect of visual excitation. It is certain that the increase of ΔS after Roentgen irradiation is due to the direct action of Roentgen rays upon the retina, but not such a general effect as has been assumed by Tarusawa *et al.*, because as mentioned above, the increase of ΔS has a direct connection with the amount of Roentgen rays scattered into the eyes from the other parts of the body. When the dose of scattered rays is over the threshold intensity, the values of ΔS show a noticeable increase after irradiation of the eye covered with a lead plate, but when the scattered rays are below the threshold intensity, the values of ΔS remain unaltered, and the same relation is observed in the experiment for irradiation of other parts of the body. As has been demonstrated by Lipetz, Roentgen rays have a desensitizing action upon the retina to light and to Roentgen rays, and in the present experiment, it has been shown that Roentgen rays also lower the responsivity of the retina to electrical stimulation. This action is caused by such a small amount of Roentgen rays as 0.5 r, and the effect is only temporary.

SUMMARY

The electrical excitability of the eyes following an irradiation of the eyes by Roentgen rays was measured by the method of electric flicker.

1. The effect of Roentgen irradiation appeared with a latency of a few minutes, and attained a maximum in about 15 to 20 minutes to disappear in about 30 to 60 minutes.

2. The effect increased with the intensity of Roentgen rays, but with doses far above the threshold intensity the effect was almost independent of the dose used. The effect depended on the total energy, but little on the stimulus duration.

3. When the eyes covered with lead plates were irradiated by Roentgen rays, some effect could be observed, and it was shown that this effect was due to the direct action of scattered Roentgen rays upon the eyes.

4. The change of ΔS , following illumination with white light for a period of 10 minutes, was measured. In this cases the time course of ΔS was different from that for Roentgen rays. The latency and the recovery time were much shorter than those for Roentgen rays.

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