ON THE ELECTRICAL REACTION OF THE RETINA WHEN EXPOSED TO Co^{60} γ-RADIATION

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The study of the action of ionizing radiation as a reflex producing factor serves as an important problem in contemporary radiobiology, and is of general biological interest. At the present time, it is believed that there is no form of receptor system in the animal organism which could be regarded as adequately radiation-sensitive. Nonetheless, there is evidence, in the radiobiological literature, of a reaction in the organism to radiation exposure as a stimulus, in the physiological sense of the word [2, 3, 6, 7, 9, 12].

The clearest phenomenon demonstrating the action of radiation as a stimulus is the generation of phosphene subsequent to passing of the radiation through the retina of the human eye. This fact became known as early as the end of the last, and the beginning of the present, century [4, etc.].

In 1901-1902, Himstedt and Nagel [8] discovered the production of an electrical reaction in the retina with exposure to Roentgen rays and radium, using the eyes of frogs and owls. Himstedt and Nagel showed that two mechanisms were responsible for formation of the electroretinogram subsequent to the action of radium rays: the direct effect of the γ-rays on the receptor elements of the retina, and the action through fluorescence, caused by the β-particles.

In the last few years, the question of production of retinal excitation secondary to the influence of ionizing radiation has been fruitfully treated by many investigators. Pape and Zakovsky [13] showed that with a 20 msec exposure, the threshold dose causing production of roentgenophosphene was equal to 0.5 mr. On the basis of mathematical computations performed under the direction of Borshtein, Pape and Zakovsky conclude that the retina must absorb 10^4 γ-quanta for the generation of a sensation of light.

Lipetz's investigations are of interest, having shown that with exposure of the ganglial cells of the retina in frogs to roentgen rays, action potentials arise in the cells, and, just as with exposure to light, some of the ganglial cells respond to the switching on of the roentgen apparatus (with the production of impulses), others respond to its switching off, a third group reacts throughout the entire period of exposure.

In 1957, Elenius and Sysimetsä [5] recorded an electrical reaction from the retina with roentgen ray irradiation of the human eye. These authors showed that the threshold dose of roentgen rays for the production of the electroretinogram (0.5 r) was 1000 times greater than that which was necessary for the subjective sensation of the action of radiation.

Our investigation was designed to study the possible mechanisms for the production of an electrical reaction in the retina secondary to the action of ionizing radiation.

METHOD

The experiments were carried out on isolated frog eyes (Rana ridibunda). The biopotentials were conducted via chlorinated silver electrodes, one of which was placed on the posterior surface of the eyeball, and the other directly touching the retina. The preparation containing the electrodes was placed in a moist chamber. The biopotentials were amplified by the use of a four-cascade alternating current amplifier. Recording of the electrical reaction in the retina was made on an ink-tracing oscillograph. The recording apparatus permitted making tracings of processes with frequencies of from 0.3 to 70 cps. As the source of radiation, we used a γ-instrument charged with radioactive cobalt (Co^{60}). Irradiation was performed in doses of 25 r/sec, 1.35 r/sec, 0.425 r/sec, 0.144 r/sec, 0.072 r/sec, 0.012 r/sec, and 0.001 r/sec. The various dose outputs were attained by changing the focal distance of the source. Duration of the irradiation was equal to 3-4 seconds. As a light stimulus, we used a 6.3 v, 0.28 amp lamp, the intensity being reduced by the use of a neutral light filter. Markings of the irradiation and light stimulus were made automatically.

RESULTS

In the first series of experiments, we studied the possibility of generating an electrical reaction in the retina by stimulating it with cobalt γ-rays (Co^{60}), and its dependence on the different dose outputs. The experiments were done in the setting of darkness adaptation. It was shown that with stimulation of the retina with gamma rays in darkness an electrical reaction is registered after a certain latent period (Fig. 1). This reaction is markedly similar to the electroretinogram arising from the action of light.

The γ-ray electroretinogram manifested certain constant features which are also characteristic for the light ERG. Thus, with an increase in the irradiation intensity, an intensification of the electrical reaction took place, along with a decrease in the latent period (see Fig. 1). With decrements in the intensity of the irradiation, the electroretinogram gradually decreases, while the effect of "switching off" lasts longer (d-wave). In our investigations, the intensity approaching the threshold was equal to approximately 0.001 r/sec.

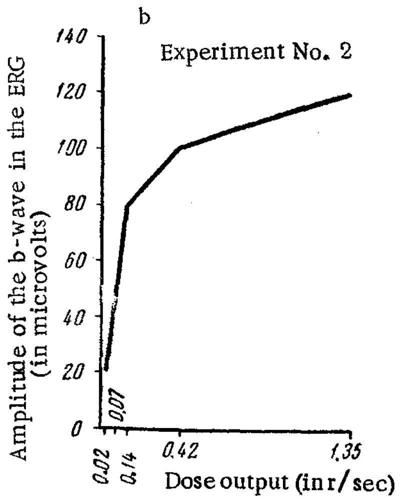

Fig. 1. Dependence of the γ-ray electroretinogram on the intensity of irradiation.

In order to be sure of the biological existence of the electrical reaction in the retina observed by us secondary to its exposure to the γ-rays of Co^{60}, we carried out experiments in which the retina was treated with a weak solution of hydrochloric acid. After death of the retina, the reaction disappeared both for light and for γ-ray stimulation.

In the second series of experiments, we studied the effect of darkness adaptation on the γ-ray electroretinogram. For this purpose, we first interrupted the adaptation and then recorded the γ-ray ERG immediately after switching off the adaptation-interrupting light. Subsequently, recordings were made after 1, 3, 5, 10, 15, 20 minutes, etc., of darkness adaptation, the amplitude of the b-waves was measured, and the curve of darkness adaptation plotted.

It is interesting to note that in a number of cases, where adaptation-interruption was inadequate, the γ-ray ERG was also observed for light. However, as the time of exposure to the adaptation-interrupting light increased, it disappeared. Subsequent darkness adaptation again restored the γ-ray electroretinogram.

It was observed that, with an increase in the time of the darkness adaptation, there occurred an enlargement of the b-wave, which then remained at a fixed level. Afterwards, in connection with the moribund state of the preparation, the amplitude of the wave gradually began to fall. It should be pointed out that in certain trials, at the beginning of darkness adaptation, the d-wave appeared earlier than the b-wave. In the course of the darkness adaptation, it first rose and then diminished.

Comparison of the curves for darkness adaptation of the γ-ray and light electroretinograms disclosed a marked similarity (Figs. 2 and 3).

Thus, the action of Co^{60} γ-rays on the frog retina adapted to darkness leads to the production of an electrical reaction which is notably similar to the electroretinogram arising from light stimulation. The electrical reaction of the retina to the γ-rays must be regarded as a response of excitable tissue to a stimulus. A clearly manifested effect of "switching-on" and "switching off" was noted in the electrical reactions of the retina recorded by us; these reactions were especially apparent with prolonged irradiations (20 seconds). Thus, the γ-rays demonstrate a stimulatory effect on the retina.

On the basis of the data obtained by us and existing in the literature, the following may be said in relation to the mechanism of the γ-ray electroretinogram.

The form of the electroretinogram, and of the ganglial cell discharges, generated by the action of irradiation shows a marked similarity to the responses of the retina to light stimulation.

In the case of γ-ray exposure, the reaction does not arise immediately, but just as in the case of light exposure, after a certain latent period.

The amplitude of the b-wave of the γ-ray ERG rises in the process of darkness adaptation, which also takes place under the influence of light stimulation, while, in the course of darkness adaptation, the d-wave first increases, and then gradually falls.

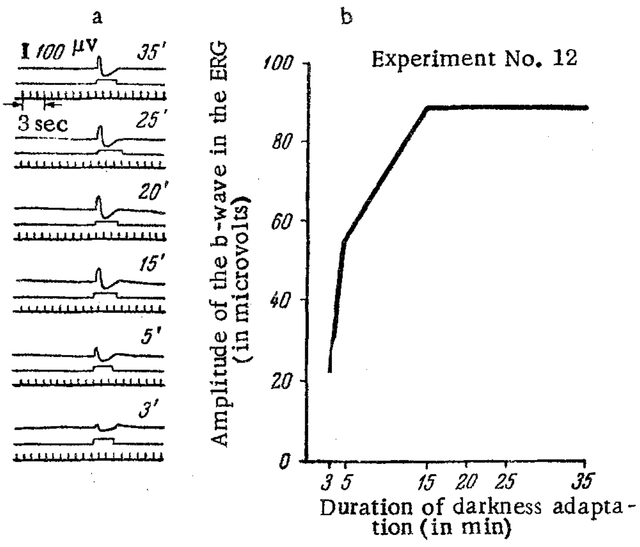

Fig. 2. Changes in the γ-ray electroretinogram with darkness adaptation. a) Copies from the original tracings of the ERG in the process of darkness adaptation (duration of darkness adaptation shown by the numbers to the right); b) graphic representation of the darkness adaptation curve.

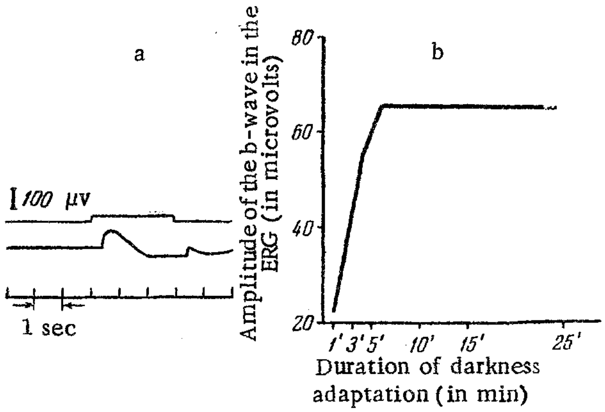

Fig. 3. Changes in the light electroretinogram with darkness adaptation. a) Light electroretinogram; b) graphic representation of the darkness adaptation curve.

With incomplete light de-adaptation, a gamma ray ERG is recorded secondary to the action of light. Increasing the time of exposure of the adaptation-interrupting light leads to disappearance of the γ-ray ERG, while subsequent darkness adaptation again leads to its generation.

All these facts, as well as proof of the bleaching of rhodopsin [14] and the decolorization of the retina [10, 11] with exposure to ionizing radiation, serve as evidence that photochemical processes are responsible for the production of the γ-ray retinogram, just as in the case of light. However, on the other hand, the possibility of a depolarizing effect of the radiation on the membranes of the neurons has not been excluded, which is pointed out by Lipetz. The concept of a depolarizing action of radiation on the synaptic apparatus has also been developed in the work of A. V. Lebedinskii and co-workers.

The effect of ionizing radiation on the photochemical processes is probably realized by dual means: on the one hand, it may be postulated that radiation has a direct action on the visual purple. However, at the present time the other point of view cannot be disproved, according to which the action of radiation energy on the biological subject being studied causes a process of ionization and excitation of the atoms and molecules, which leads to an exchange of energy, microfluorescence of the intraretinal elements, and radiation of energy sufficient for the visual analyzer.

SUMMARY

Electrical reaction of the retina was noted as a result of the action of Co^{60} γ-rays upon the isolated frog eye. This reaction and some of its regularities are very similar to the electroretinogram appearing in light stimulation of the eye. Analysis of the data here and literature data has led to a suggestion that photochemical processes are of great significance in the mechanism of radiation phosphene formation.

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