EFFECTS OF INJURY TO MICE BY MICROWAVE (2400 mHz) IRRADIATION AND SUBSEQUENT RECOVERY

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Threshold values of power density (PD) and exposure at which the mortality did not exceed 0.1% were determined in experiments on 2200 mice. The rate of formation of the pathological changes and of repair reactions was found to be close to an exponential function of PD. The functional relations established describe the adaptive powers of mice to microwave irradiation quantitatively.

KEY WORDS: microwave irradiation; adaptation.

Data on the mortality among mice following microwave irradiation with different parameters were described previously [3-8]. In most cases the object of those investigations was to obtain the threshold times of "zero" or "absolute" mortality among animals in order to study responses of different systems at the sublethal level or the pathophysiological characteristics of the lethal effect itself. Quantitative analysis of these data from the standpoint of type of effect (mortality) versus duration of irradiation relationships is impossible because in most cases the necessary information on effects intermediate between "zero" and "absolute" death of the animals is not available.

The object of this investigation was to detect the relationship between the effect (mortality) and duration of irradiation at various power densities (PD) and also the relationship between PD and duration of exposure to give identical levels of effect.

EXPERIMENTAL METHOD

Experiments were carried out on 2200 noninbred female mice weighing 22-24 g. Irradiation was carried out in the far zone of a continuous radiation electromagnetic field (frequency 2400 mHz), generated by the Parus apparatus (power 2.5 kW). The mice (four in a batch) were placed in a naturally ventilated (0.5 liter/min) Plexiglas chamber with four separate sections. The long axis of the animals forms a tangent to the surface of the incident electromagnetic wave, i.e., it was perpendicular to the vectors $\vec{S}$ and $\vec{E}$ and parallel to the vector $\vec{H}$. The front of the incident electromagnetic wave coincided with the lateral surface of the animal. To improve the characteristics of the electromagnetic field a special anechoic chamber was used, which ensured inequality of distribution of power of not more than 1 dB for animals of this species. The mean air temperature in the chamber during a 30-day experiment in May was 21.0±1.0°C. The mice were irradiated with microwaves with an exposure PD of 800, 500, 300, 200, 100, 80, and 60 mV/cm². PD was measured with the PO-1 instrument (Medik) in conjunction with an additional graduated attenuator. Absence of pulse and breathing served as the criterion of death of the animals. Observations on the animals continued for several days (not less than 2). Agreement between empirical and theoretical determinations was estimated by Pearson's and Kolmogorov's criteria.

EXPERIMENTAL RESULTS AND DISCUSSION

Distribution of the lethal effect as a function of duration of irradiation at different values of PD of microwave irradiation is illustrated in Fig. 1. The corresponding equations were found (by probit analysis) for each function:

$$Y = 10{,}67X + 7{,}78;\ Y = 11{,}04X + 6.47;$$
$$Y = 15.2X + 2{,}9;\ Y = 17.23X + 0.13;\ Y = 16{,}73X - 8{,}15;\ Y = 11{,}23X - 7{,}0;\ Y = 8.34X - 5{,}93,$$

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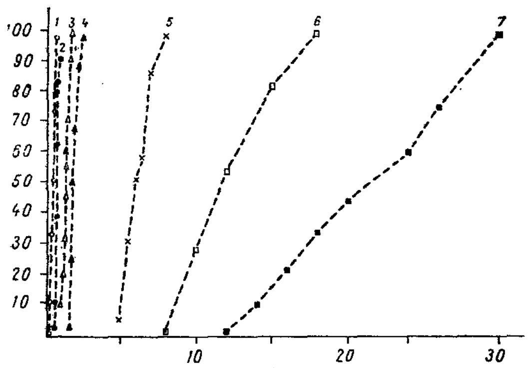

Fig. 1

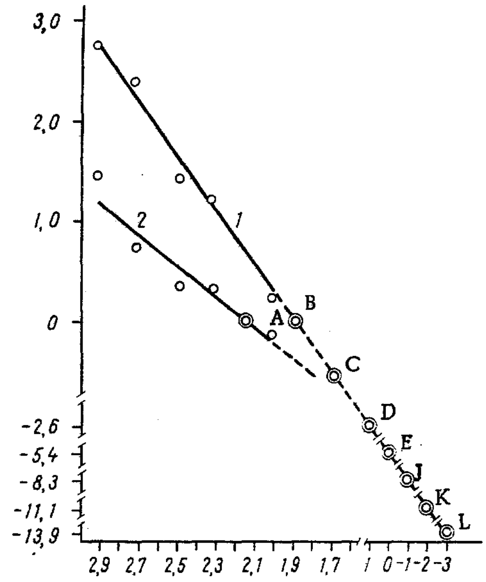

Fig. 2

Fig. 1. Death of mice as a function of duration of irradiation. Abscissa, duration of irradiation (in min); ordinate, death of animals (in %). 1-7) Empirical distributions corresponding to PD values of 800, 300, 200, 100, 80, and 60 mW/cm^2.

Fig. 2. Ratio of rate of injury to rate of recovery as a function of PD of microwave irradiation. Abscissa, log PD (in mW/cm^2); ordinate, log of ratio of rate of injury (in %/0.1 min) to rate of recovery (in %/0.1 min). 1, 2) Levels of injury and recovery of 0.1% (99.9%) and 50.0% (50.0%) respectively. 1) $\log Y = -5.4429 + 2.8460 \log X$; 2) $\log Y = -3.5093 + 1.6364 \log X$). Remainder of explanation in text.

where Y is the lethal effect (in probits); X the logarithm of the time of irradiation (in min). Analysis of the data showed the existence of two interconnected processes: an increase in the time taken to produce an assigned effect and a decrease in the angle of slope of the distributions with a decrease in PD.

The relationship between PD and time taken to reach an equal effect, say 0.1, 50, and 99%, is in fact interpolated by the corresponding equations of an exponential function:

$$\log Y = 2.4333 - 0.7408 \log X; \log Y = 2.6087 - 0.6800 \log X; \log Y = 2.7402 - 0.6023 \log X,$$

where Y denotes PD (in mW/cm^2); X the duration of irradiation (in min). The nonlinear character of the equal effect curves indirectly points to the presence of reparative processes (as a first approximation, the elimination of heat), with a complex biophysical nature, and with an intensity which increases as PD falls. The definite similarity between the results and theoretical calculations [5] suggests that at PD values of below 40±10 mW/cm^2 the biophysical mechanisms controlling the heat balance in mice become so efficient that the elimination of heat takes place in the course of a period of time that is always shorter than the duration of irradiation. The results of previous experiments [1, 8] and of the present series with daily exposure (for 60 and 10 min, in a single session, time limit corresponding to observance of the standard of hygiene accepted for the experiment) for 1 and 3 months (21 and 90 exposures respectively) with PD of 40 mW/cm^2, in which mortality among the animals did not exceed 0.1%, confirm these suggestions.

It was shown previously [1] that if the time required to reach a lethal effect of microwave irradiation 90±10% for example, is divided into equal sections and the interval between them is gradually increased, the survival rate of the animals rises, and when the interval between periods of irradiation reaches a certain value, death of the animals is no longer observed, and the rate of this process is inversely proportional to the level of PD. At PD of 800, 500, 300, 200 and 100 mW/cm^2 this tendency, which was estimated to be a repair reaction, was interpolated by the following equation (probit analysis):

$$Y = 2.0755 \cdot X + 3.93;\ Y = 5.86 \cdot X + 2.86;$$
$$Y = 7.25 \cdot X + 3.37;$$
$$Y = 6.96 \cdot X + 3.14;\ Y = 4.19 \cdot X + 3.35.$$

where Y is the survival rate (in probits); X the logarithm of time between individual exposures to irradiation (in min).

On the basis of these results it was possible to assess the ratio between the rate of injury and the rate of recovery for comparable levels of effect (for example 0.1% mortality — 99.9% survival; 50.0% mortality — 50.0% survival) as a function of PD of microwave irradiation. Within the limits of PD studied, this relationship is interpolated in Fig. 2 by equations of an exponential function:

$$\log Y = -5.4429 + 2.8460 \log X \text{ and } \log Y = -3.5093 + 1.6364 \log X.$$

Assuming that this ratio is equal to unity (the optimum for maximal manifestation of the adaptive powers of animals of this species) absence of mortality may be expected under these conditions. In reality, with this ratio PD was 140 and 81.8 mW/cm^2 (the projection of points A and B on the abscissa; see Fig. 2). The experimental results indicate that these intensities of microwave irradiation produce mortality effects of between 0.1 and 99.9%. The projection of point C on the abscissa (Fig. 2) indicates the actual value of PD at which the type of effect (mortality) can no longer be shown to depend on the duration of irradiation, and the ratio under these circumstances is 0.22, i.e., much lower than the hypothetical value (1.0). With a decrease in PD this ratio falls even more and, consequently, the ability of the mice to compensate the harmful action of the microwaves is increased. For instance, at PD values of 10 and 1 mW/cm^2 and 100, 10, and 1 $\mu W/cm^2$ the logarithms of these ratios are −2.5939, −5.4429, −8.2889, −11.1349, and −13.9809 (points D, E, J, K, L respectively; see Fig. 2).

The experimental results thus enable some of the factors in the harmful action of microwaves and of the repair reactions taking place under these circumstances to be estimated as a first approximation. For animals of this species there are threshold values of PD and of the duration of microwave irradiation at which the mortality level does not exceed 0.1%. The relationship between PD and the duration of irradiation can be represented by the equation of an exponential function. This level can be called the level of indeterminate mortality, i.e., a level not exceeding the natural background mortality of the animals, when it is difficult to identify any contribution of the acting factor to the final effect or it may be equal to the contributions of other factors causing natural death. The ratio between the rates of formation of injury and the rate of restorative reactions taking place under these circumstances (at the level of indeterminate mortality) is a function of PD of microwave irradiation. Assuming that microwave energy is transformed into heat at low values of PD, the relationship thus obtained may describe quantitatively the adaptive powers of animals of this species during exposure to low-intensity irradiation.

The tendencies described above apply to relations between the processes of injury and recovery during single exposures to irradiation, but the experimental data on detection of cumulative effects of microwave irradiation [2] justify the extension of the views expressed to repeated (chronic) irradiation also.

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